WESTERN AUSTRALIAN INSTITUTION

OF

ENGINEERS.

PROCEEDINGS.

VOLUME 5.

No. 1.

NOVEMBER, 1914.

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PROCEEDINGS

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EDWARD SHOTTON HUME, M. Inst. M.E.,
President 1914-1915.

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PROCEEDINGS—WESTERN AUSTRALIAN INSTITUTION OF ENGINEERS.

PAPERS AND DISCUSSIONS.

PRESIDENTIAL ADDRESS.

(BY E. S. HUME.)

Allow me to thank you for the great honor you have bestowed on me by electing me President of the Institution. At the same time, I fully realise that had not Mr. W. C. Reynoldson decided to take up farming and reside at too great a distance from Perth to look after the duties connected with that office, he would have been your President, and not I, and you would, no doubt, have been the gainers. However, as such is not possible, with your assistance I will endeavor to do all in my power to advance the interests of this Institution.

In framing the address which is expected from the President at the opening of the yearly session, and following the usual character of the addresses submitted by the previous presidents on such occasions, it has occurred to me that it would be interesting to place on record the advance that has been made in connection with locomotives and rolling stock in this State since the introduction of railways, and to touch on other points related thereto.

LOCOMOTIVES.

The first account we have of a railway in Western Australia is that of a line constructed to the Darling Range from the coast,

a few miles north of Busselton, in 1871. That line carried the first locomotive brought into this State, the engine being four-wheel coupled, with a tender, and it was appropriately named "Ballarat," from the Victorian town of that name, where it was manufactured by the Phoenix Foundry Co. As the haulage power of this locomotive is not known to me, I am unable to contrast it with those used on Government lines to-day, particulars of which are given in appended table. The first locomotives used on Government lines were the old class "M" Nos. 23 and 24, which were built in Great Britain in 1875 and taken over by the Government from the contractors who constructed the line from Geraldton to Northampton, which was completed in 1879. The engines worked in that district for a considerable number of years, and after doing service elsewhere were sold by the Government and are still at work on lines connected with two timber propositions in the South-West. When the line from Fremantle to Guildford was completed in 1881, the locomotives first introduced were of small capacity as compared with the modern types now in use. Compare, for instance, the tractive power of the class "A" engines (which at one time ran the mail trains) of 7,200 lbs. with the tractive force of 16,156 lbs. exerted by the present-day express locomotives.

In Table No. 1, it will be seen that the range of tractive power is very extensive, varying from 3,780 lbs. of the pigmy "H" class (which is still suitable for work on jetties whose structures will only carry a light load) to the 23,445 lbs. of the class "Fs" heavy goods locomotive, working with superheated steam, which requires a 60-lb. rail and proportionately strong bridges to carry its 86 tons weight in working trim.

The table does not include two locomotives of the double "Fairlie" type which were used on the railways. The date they were placed on traffic is not definitely known, but their life as railway tractors was short. This type of locomotive had two boilers, the engines being carried on separate bogies at either end of the main frame, so that it could run with equal facility in either direction. However, they were not a success. One was cut into two parts, and the half engine worked as a shunting locomotive for some years before being sold to a timber company. It appears in Table 1 as old "F" class.

The latest type of locomotive introduced into Australia is the "Garratt," of which examples are running in this State and in Tasmania. The use of this type has rendered it possible to haul as much on tracks laid with 45-lb. rails as with locomotives of the conventional type on the 60-lb. rails. The tractive power of the two types, non-superheated, is: class "F" (heaviest ordinary locomotive) 20,525 lbs., class "M" (Garratt type) 21,030

lbs. In addition, the latter machine, not having a tender, can go and bring in a full load where no provision in the shape of a triangle or turntable has been made. In the case of the ordinary type, when running tender-first, the load has to be reduced on main line by 25 per cent., and the speed checked to a corresponding extent.

The general increase in the tractive power of locomotives in use has naturally been followed by a proportionate increase in the loads hauled. To compare extremes: the Northampton engine would haul 82 tons up a 1 in 45 grade, as against 275 tons for the class "F." The average cost of working these engines has been found to be 12.64d. and 21.3d. per train mile respectively. At the old "M" rate, therefore, the cost of hauling the "F" class load would be no less than 42.4d. per train mile. Not only is the economical value of the larger engines shown in lesser actual cost, but by being enabled to haul larger loads a greater volume of traffic can be hauled along single tracks with fewer crossing sidings. On comparatively level tracks, our heaviest goods locomotives now take a gross load behind the tender of 750 tons—this on what is termed a "narrow gauge" railway.

By the use of superheated steam, a reduction of 35 per cent. in the coal bill and 38 per cent. in the consumption of water is brought about. This result really brings our locomotives when using Collie coal up to the same efficiency as the non-superheated work at when New South Wales coal is used. The cost of boiler repairs is correspondingly reduced by the smaller amount of water evaporated, and the engine repairs are lessened by the reduction of back pressure due to increased size of the exhaust nozzle. The larger nozzle is rendered possible by smaller consumption per foot of grate area.

No advantage has been found in this State with the compound type locomotive over that of the saturated steam simple locomotive of the same size. The cost per mile per 100 tons hauling power works out as follows:—Simple engine, class "E" 6.49d.; compound engine, class "Ec" 7.54d.; this cost includes repairs.

Reviewing the locomotives as per Table 1, it will be seen that the first locomotives introduced were of small capacity in accordance with the work that was required and the weight of rails. With the introduction from 1893 to 1896 of the classes "K," "N" and "O" goods locomotives, much greater train loads were taken, which was made possible by the provision of a heavier rail to carry the heavy locomotives. A further advance occurred in 1901-02 when the lighter express engines were superseded by the "E" and "Ec," and the heavy goods class "F" was also put on the road. The latest improvement has taken

place during 1912-13 by the adoption of the superheated system on class "F" and the introduction of the "K" class (Garratt type)—both saturated steam and superheated.

Devices for Economical Working of Locomotives.

Other devices which assist in economical locomotive working are exhaust injectors and hot water injectors, and improvements to exhaust nozzles.

With reference to the exhaust injector, comparative tests conducted under severe working conditions showed a saving of 12 per cent. in coal consumption in favor of the exhaust instruments as against the ordinary type of injector. The best results were obtained when working the former instruments on long runs. The exhaust instruments will not supersede the live steam injector for all classes of work, but with one instrument of this type on one side of the locomotive, and an ordinary injector on the other side, economical results can be obtained.

Hot water injectors have not been quite so successful, although the fitting of ordinary injectors with hot water cones has given some improvement. We are now on the point of trying a system of feed water heating with pump to take the place of the injector, and as the action of the pump is independent of the temperature of the water it deals with, it is expected that further economy will be secured.

Extensive experiments were carried out with exhaust nozzles, and these have shown that the "Star" pattern as per diagram is the most suitable and economical.

Water Supplies.

Considerable difficulties exist in working traffic in this State owing to the inferior quality of much of the water available—which is common where the original forest has been removed or trees ring-barked. In certain districts, unless the reservoirs are filled by a thunderstorm or heavy rain, the water, which trickles slowly along, becomes highly impregnated with alkaline chlorides. It is necessary to test the water which is running, and only allow it to go into the dam when tests show that the salts held in solution are not above a certain figure. In some instances where the salt areas have been located, it has been possible to divert water from such spots away from the dam, and only permit water to drain in from that part of the watershed which is not contaminated. For example:—

Case (1).—At Cranbrook, G.S.R., the water became very bad. On testing the area, the source of contamination was located, and the bad water diverted, as shown on drawing No

1964. The quality of the water in the dam at once improved, and has remained comparatively good.

Case (2).—At Wagin the water which used to be conserved when the watershed was virgin bush, in 1903 contained 9.12 grains of alkaline chlorides and no magnesium chlorides. Analysis of water taken from the same dam on December 7, 1912, indicated 92.6 grains of alkaline chlorides and 5.5 magnesium chlorides. In this case the area of contamination was definitely located, but it was considered that the expense of providing a cement drain to carry the water through the salt patch was too great. By watching and testing the flow of the water in the creek after heavy rain, however, we have been enabled to recently secure a dam full of water carrying not more than 14 grains of salt per gallon.

Case (3).—When testing water along creeks flowing through ring-barked country at Yornaning in June, 1909, the results as per drawing No. 1,963 were obtained, showing that while the water from the virgin wooded country contained under 10 grains of salt per gallon, the water from the cleared country along the Hotham River was so salt as to bring the water in the pool up to 106 grains in the river end, and by diffusion raise the salt in the leg of the pool (which received the better water) to 65.5 grains.

There are further examples where, through land being cleared, the waters of dams and pools have ceased to be made use of owing to their bad quality, viz.:—

Spencer's Brook	108
Clackline	100
Northam	60
Burlong Pool........	150

Coal.

In comparison with the Eastern States, much difficulty is experienced here with the local coal. The standard calorific value of Collie coal is put down as 10,500 British thermal units, whereas the standard value of Newcastle (N.S.W.) coal may be stated approximately at 14,050 B.T.U., the latter thus having a greater laboratory value of practically 34 per cent.

Unfortunately, our local product cannot be stored on account of its large percentage of moisture. The tendency to spark, especially during the summer months, when the evaporation is greatest, is a drawback. Owing to the lesser risk of fire from its use, Newcastle coal only is burned in the agricultural areas during the three harvest months. When using Collie coal during the summer months the abrasion of the boiler tubes is also much greater on account of the larger quantity of small coal being carried through. The deterioration of Newcastle coal by exposure

is comparatively *nil*, and it is therefore possible to store it during the slacker months at the various depots in anticipation of the increased demand in the summer time. By this means, engines which would be engaged hauling coal in our busy months are more profitably engaged in meeting the public demand for quick transit of produce.

Efforts are being made to improve the results obtained from the local coal by the introduction of an ash and smoke consumer. An appliance of this description is now being fitted.

Rolling Stock.

The length and width of carriages running on the Western Australian Railways compares favorably with those on the 4 ft. 8½ in. and 5 ft. 3 in. lines of the Eastern States. We were the first to introduce dining cars into the Commonwealth, and they have been running continuously between Perth and Kalgoorlie since their first adoption in March, 1905.

Two hundred and sixty carriages are fitted with dynamos for generating electric light. The system has proved very successful, and the annual cost of maintenance of the electric light per car has been reduced from a maximum of £32 16s. per car to £14 9s. 2d., the latter being the cost in 1913.

As with locomotives, the earlier types of carriages were small and of limited capacity. Compare the "AI" four-wheeled car, having seating capacity for 18 passengers, with the "AT" second-class suburban car, seating 90 passengers, and the "AQ" first-class long distance corridor car (seating capacity 33, sleeping capacity 22). Diagrams of these cars Nos. 16, 30 and 25, are appended, also diagram No. 32 of "AV" dining car, which has provision for seating 24 diners, as well as kitchen accommodation.

Vacuum Brake.

The continuous automatic brake is the standard for controlling trains in this State. All locomotives, carriages, and express brakevans have been completely fitted. Of the total of 9,046 other vehicles, 63 per cent. have been fully equipped with vacuum brakes, and the remainder with train pipe only, which permits the vacuum to be worked continuously the whole length of all trains.

The vacuum brake gives practically no trouble, is easily maintained, and its use and manipulation are readily learned by skilled or unskilled employees. The cost of upkeep is small, and it has been necessary to hold only few spares in stock. One essential feature is the obtaining of the best quality of india-rubber for hose connections, rubber rings, diaphragms, and piston rod bushes.

Wheels and Axles.

The introduction of our present car and wagon standard axle with a journal $7\frac{1}{2}$ in. x 4 in. has enabled the carrying capacity of four-wheel stock to be increased by 28 per cent., and the bogie stock by 33 per cent., and the adoption of a heavier axle with journal 8 in. x $4\frac{1}{2}$ in. has enabled larger bogie trucks to be put on the line with a nett carrying capacity up to 27 tons each.

At the beginning of our railway life it was the standard practice to key on the wheels of trucks and carriages, and also to form a square shoulder behind the wheel boss against which the wheels were pressed on. (See drawing No. 2,492.) This practice was responsible for a great number of axles failing immediately behind the boss of the wheel at the angle formed by shoulder and wheel seat. The present practice is to form axles as per drawing No. 1, and to bore out the boss of the wheel until it requires a pressure of 9-11 *D* tons to force the wheel on to the axle, *D* representing the diameter of the axle in inches at the wheel seat.

Improved Quality of Material.

Advances made in the quality of steel have been of great benefit in adding to the strength of parts which as originally designed were too weak. (This condition is very often brought about by the desire of the designing engineer or maker to get as large a tractive power as possible without going beyond the weight limit per axle, which is $\frac{2 \times W,}{10}$ *W* representing the weight of the rail per yard in pounds.) The tensile strength of steel used for say crank pins, axles, and piston rods was 35-40 tons; that of nickel chrome steel is 50-55 tons.

As an illustration: Our "N" class locomotives were continually breaking the driving crank pins. Formula shown on diagram No. 1,810 discloses their weakness, the factor of safety being 3.66, whereas by the use of nickel chrome steel the factor of safety was brought up to 5.6 and the failures put an end to.

By the use of high-speed steel for turning tools and for other purposes, it has been possible to do as much as seven times the amount per machine as was the case fourteen years ago, and work can now be undertaken which could not have been dealt with by automatic and turret machines at that period.

Education of Apprentices.

Coupled with the alterations and improvements that have been brought about in the railway service, the education of workshop apprentices has not been overlooked.

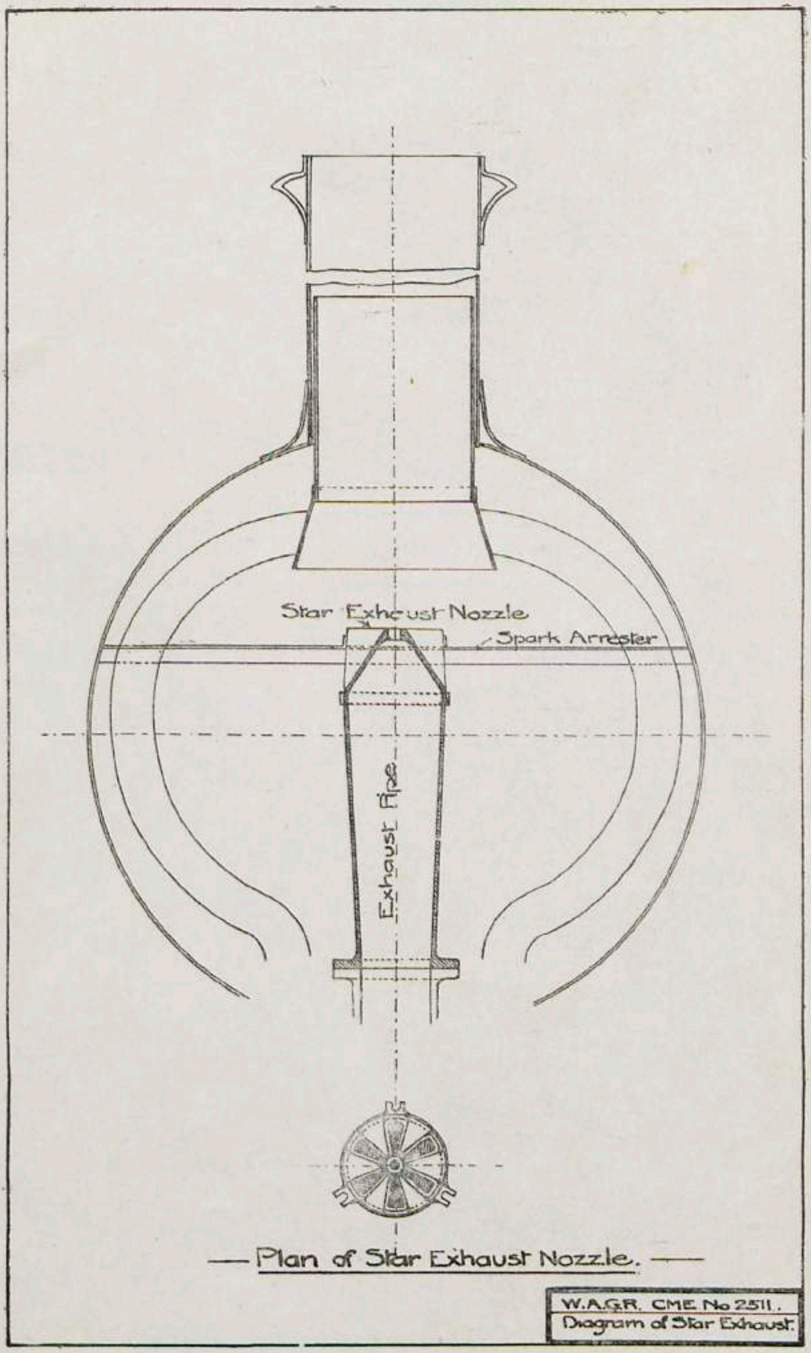
In the year 1908 steps were taken to give the apprentices (numbering 103) instruction in class-room two mornings weekly before they entered the workshop, the apprentices being paid for the time so spent. The subjects were :—Elementary class : arithmetic, mensuration ; intermediate class : algebra, arithmetic, and more advanced mensuration ; advanced class : mechanics, steam and the steam engine, and drawing. The classes were conducted wholly by railway officers for the first year. In 1909, fifteen of the more advanced boys were sent to the Technical School, the majority being taught by railway officers. The same division was observed in 1910 and 1911, but during 1912 the whole of the teaching was transferred to the Technical School authorities. The whole of the apprentices are now taught for the first three years of their term, while thirteen of the more meritorious are given advanced tuition in their fourth and fifth years. 107 apprentices are now receiving instruction.

The best of the lads so trained are being used in the Test Room, the Drawing Office, and on other important work, and the results obtained give every indication that the expenditure has been warranted. Previous to this general education of apprentices, special lads were trained as Mechanical Engineering Cadets, but with one exception all these youths left the service to take up outside work. On account of the larger number now being trained, some of them are beginning to realise that this is a large State, and that as good opportunities must become available here as can be obtained elsewhere, and they will benefit as well as the State when that fact is more generally known and recognised.

Two of the youths trained as above entered for the course of engineering training at the University last year, one attending during the day and the other at the evening classes. One of them has just been appointed to instruct the mechanical drawing students at the Technical School evening classes, in addition to attending to his ordinary duties at the Test Room, Midland Junction. The other is having his range of knowledge extended at the tramway repair sheds and office. This is rendered possible since the Government Railways Department took over that service and decided to put down a new power house to supply current for the tramways and to the Perth City Council (for power and lighting) and to others who may desire to use the current outside the radius controlled by the Council. The new power house will also supply the current for running the plant at the Midland Junction workshops.

Table I.—Western Australian Government Railways—Particulars of Locomotives since 1879.

Class.	Number obtained.	Year type was introduced on railways.	Maker whether British or American.	Original boiler pressure. Lbs.	Size of cylinder. D S.	Diameter of coupled wheels. Ins.	Arrangement of engine wheels.	Number of tender wheels.	Tractive power at ¾ boiler pressure. Lbs.	Total weight in working trim. Engine T. C.	Total weight in working trim. Tender T. C.	Water capacity. Gal.	Fuel capacity. Cwt.
M (Old)	2	1879	British	140	12" x 20"	39	2–6–0	4	7,743	18–10	11–10	660	60
C (Old)	2	1883	Do.	120	10½" x 18"	36	0–6–0	4	5,788	18–19	7– 1	950	25
A	8	1883	Do.	130	12" x 20"	39	2–6–0	4	7,200	19–12	10–15	832	30
D (Old)	1	1884	Do.	120	9" x 14"	28	0–4–0	—	4,252	12– 8	—	250	12
B	11	1884	Do.	150	14" x 21"	37	4–6–0	—	12,515	32– 0	—	600	30
S	2	1888	Do.	125	11½" x 15"	35½	0–6–0	—	5,239	17– 0	—	350	10
T	10	1888	Do.	140	15" x 20"	52	4–4–0	6	9,086	29–16	20– 0	1,700	50
G	52	1889	British & Australian	140	14½" x 20"	39	2–6–0	6	11,321	25– 4	16– 8	1,600	40
H	2	1890	British	120	9" x 14"	27	0–6–0	—	3,780	14– 1	—	300	15
L	1	1891	Do.	125	14" x 20"	39	0–6–2	—	10,554	30– 0	—	656	30
I	3	1891	Do.	120	13" x 16"	36½	0–6–4	—	7,778	37– 0	—	850	40
J	3	1892	Do.	140	15" x 22"	42½	4–6–0	6	1,229	29–12	19– 9	1,900	40
F (Old)	1	1893	Do.	120	10" x 18"	39	2–4–2	—	4,846	23– 0	—	620	20
K	24	1893	Do.	160	17" x 21"	38	2–8–4	—	19,165	53– 0	—	2,000	55
P	2	1896	Australian	140	15" x 20"	54	4–4–0	8	8,750	27– 1	24– 0	1,750	50
Q	6	1896	British	140	15" x 22"	42½	4–6–2	—	12,229	46– 4	—	1,200	50
N	42	1896	Do.	160	15½ x 21"	48	4–4–4	—	12,613	44– 4	—	1,600	40
O	45	1896	Do.	170	15½" x 21"	36	2–8–0	8	17,868	35–14	26– 5	2,000	70
R	24	1897	Do.	160	16" x 22"	57	4–4–0	8	11,857	31–16	24– 0	2,000	70
Ec	20	1901	American	200	12" x 22" } 20" x 22" }	54	4–6–2	8	16,622	46– 8	28–12	2,500	100
C	12	1902	Do.	175	16½" x 22"	49	4–6–0	8	16,043	39– 0	28–10	2,500	100
F	55	1902	British	175	17" x 23"	42½	4–8–0	8	20,525	53– 7	28– 1	2,200	100
E	65	1902	Do.	175	17" x 23"	54	4–6–2	8	16,156	53– 4	30– 0	2,200	100
U	1	1904	Do.	180	14" x 20"	36	0–6–0	—	14,700	37–14	—	540	30
Qa	4	1905	Do.	175	15" x 22"	42½	4–6–4	—	15,287	46– 4	—	1,600	55
Oa	10	1909	Do.	170	15½" x 21"	42½	2–8–0	8	15,135	38–15	23–19	2,000	70
M	6	1912	Do.	175	12½" x 20"	39	2–6–6–2	—	21,030	66–10	—	2,000	70
D	20	1912	Do.	175	17" x 23"	54	4–6–4	—	16,160	68–10	—	1,600	80
Fs	2	1912	Do.	160	19" x 23"	42½	4–8–0	8	23,445	55– 7	30–12	2,200	110
Ms	6	1913	Do.	160	13¼" x 20"	39	2–6–6–2	—	21,608	69–16	—	2,000	60

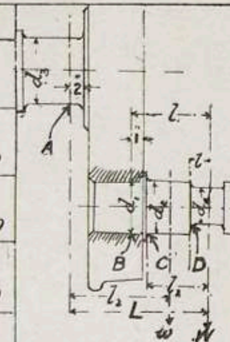

Star Exhaust Nozzle
Spark Arrester
Exhaust Pipe
— Plan of Star Exhaust Nozzle. —
W.A.G.R. CME No 2511.
Diagram of Star Exhaust.

W.A.G.R

Examples of Bearing Pressures & Stresses in Existing Engines.

Designed by	Class	No. Wheels Coupled	Steam Press. □	Diam. of Cylinder	Length & Diam. of Journal & Bearing Press. □: Axle	Connecting Rod Pin	Coupling Rod Pins: Driver	Coupling Rod Pins: Lead.[g] Tr.[g]	L	Stresses per □ on Material: Axles at A: Due to W.L	Axles at A: Due to WL−wl₁	Crank Pin at B	Pin at C	Pin at D
W.A.G.R.	E	6	175	17	8 × 7 209	4½ × 4¾ 1204	3⅞ × 5½ 1102	3⅞ × 4½ 683	15 1/16	(19600) 15690	13350	13220	(16050) 13960	7840
Neilson	N	4	160	15½	9 × 6¼ 189	3¾ × 3¾ 1933	3⅝ × 4¼ 882	3⅝ × 4¼ 882	13	(18580) 14475	9290	22930	(23330) 19450	9660
Baldwin	C	6	180	16½	7 × 6½ 170	5 × 5 1385	4 × 5½ 1049	3½ × 3½ 941	15	(24030) 18870	10290	14340	(15560) 13530	6920
Neilson	K	8	160	17	9 × 7 approx. 128	4½ × 4¾ 1709	4 × 4¾ 1290	3½ × 3½ 667	14¼	(16970) 13580	6615	22150	(22430) 19060	9580
Hawthorn Leslie	Q	6	160	15	9 × 6 approx. 145	4½ × 4 1568	3 5/16 × 4½ 1140	2 13/16 × 3¼ 929	14⅝	(22400) 17250	10278	22860	(23740) 20000	14340
Dubs	R	4	160	16	8 × 6½ 195	4½ × 4 1608	3 × 3 1608	3 × 3 1608	10¾	(14400) 11335	5617	12250	(12350) 10175	8040
Formulæ used in Calculations					$\frac{P-x}{a}$	$\frac{W}{a}$	$W\frac{\frac{n-1}{n}}{a}$	$\frac{W}{na}$		$\frac{WL}{d_1^3 \cdot 1}$	$\frac{WL-wl_1}{d_1^3 \cdot 1}$	$\frac{wl}{d^3 \cdot 1}$	$\frac{wl_2}{d_1^3 \cdot 1}$	$\frac{Wl}{d_2^3 \cdot 1}$
No. of Column	1	2	3	4	5	6	7	8	9	10	11	12	13	14

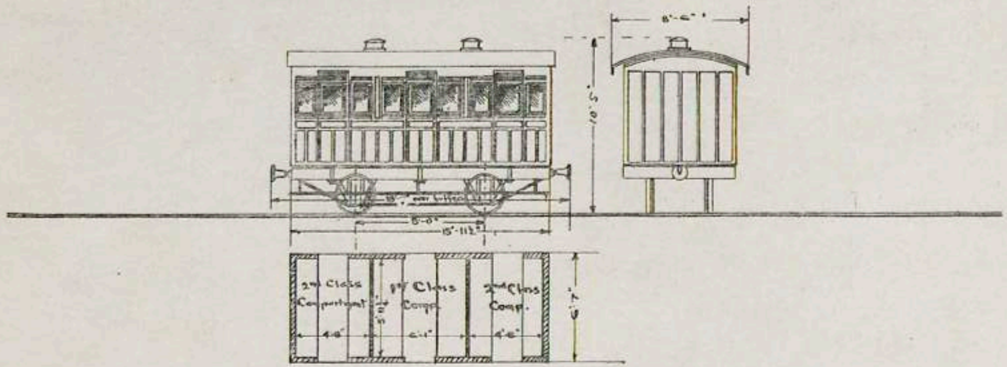
Figures in brackets in column 10 show stresses with ½" reduction of axle diameter.
Do. " 13 " " ½" " crank pin " .



a = Area of bearing.
n = No. of Wheels coupled.
x. Weight of Wheels, Axles, &c.
P. Load at rails.
p. Boiler Steam press.
W = ·9 p × Cylinder area.
w. Load transmitted to other wheels.

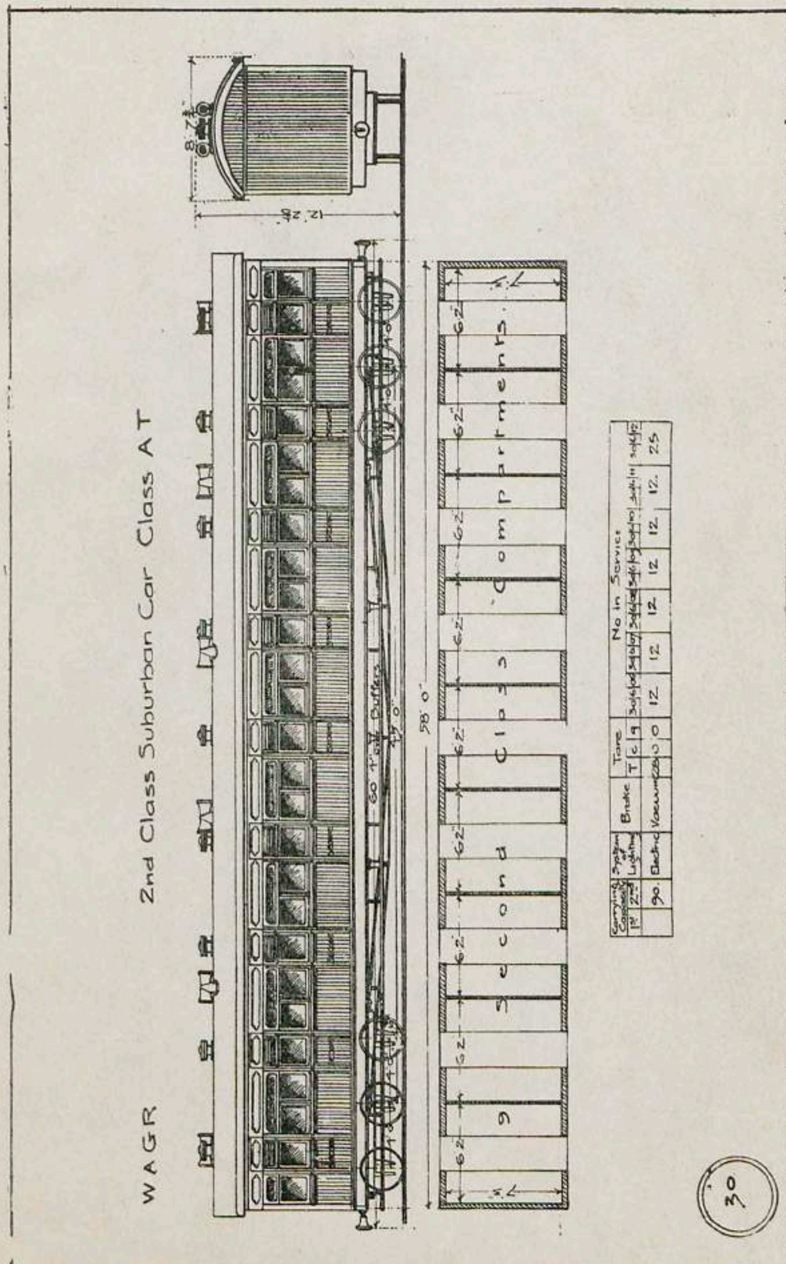
Instead of $d^3 \cdot 0982$, d^3 is taken for simplicity.

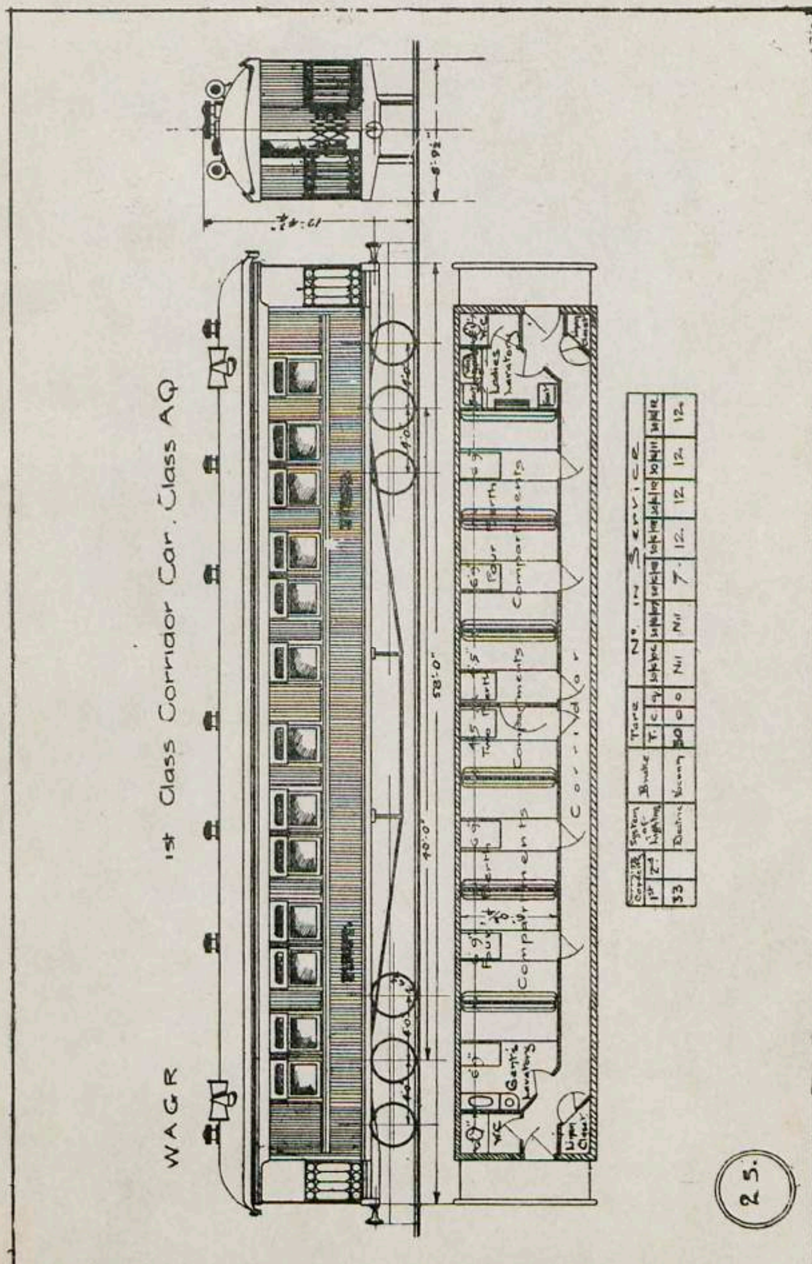
W.A.G.R. Composite Car. Class A1.

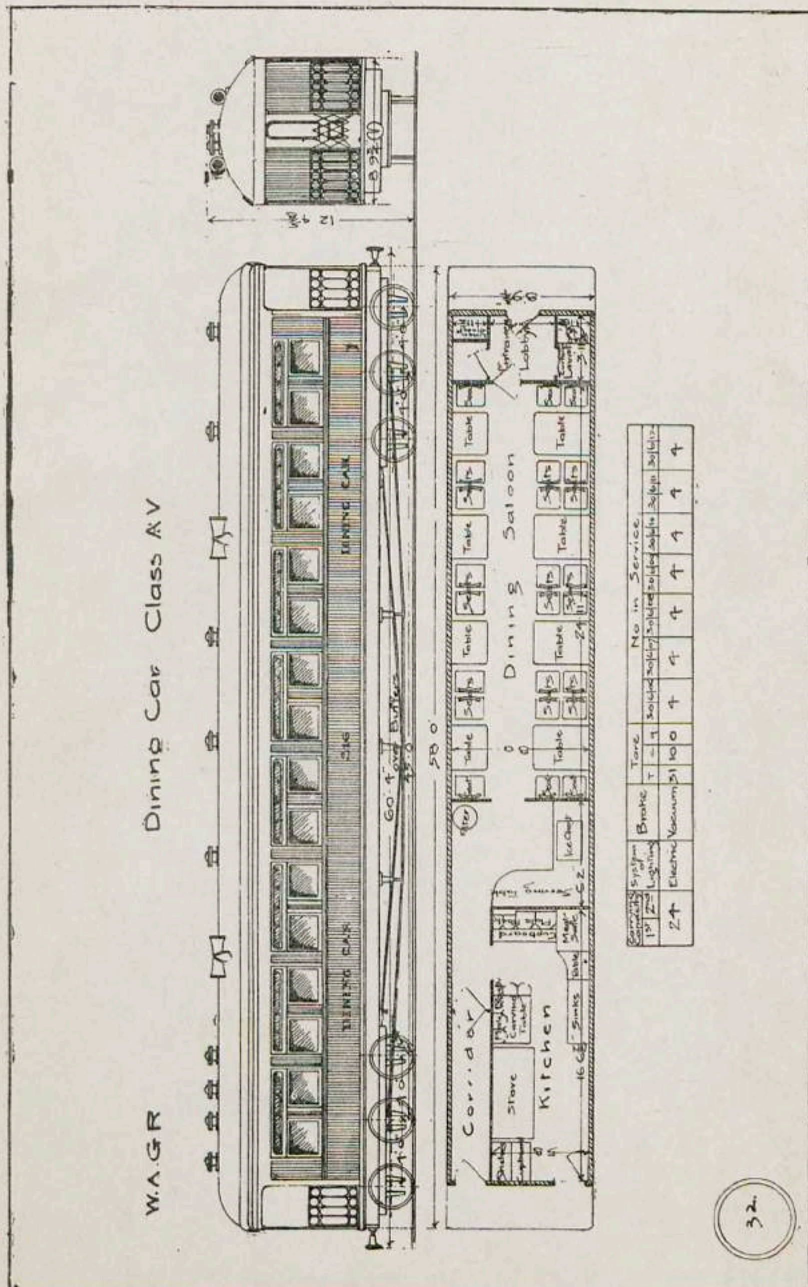


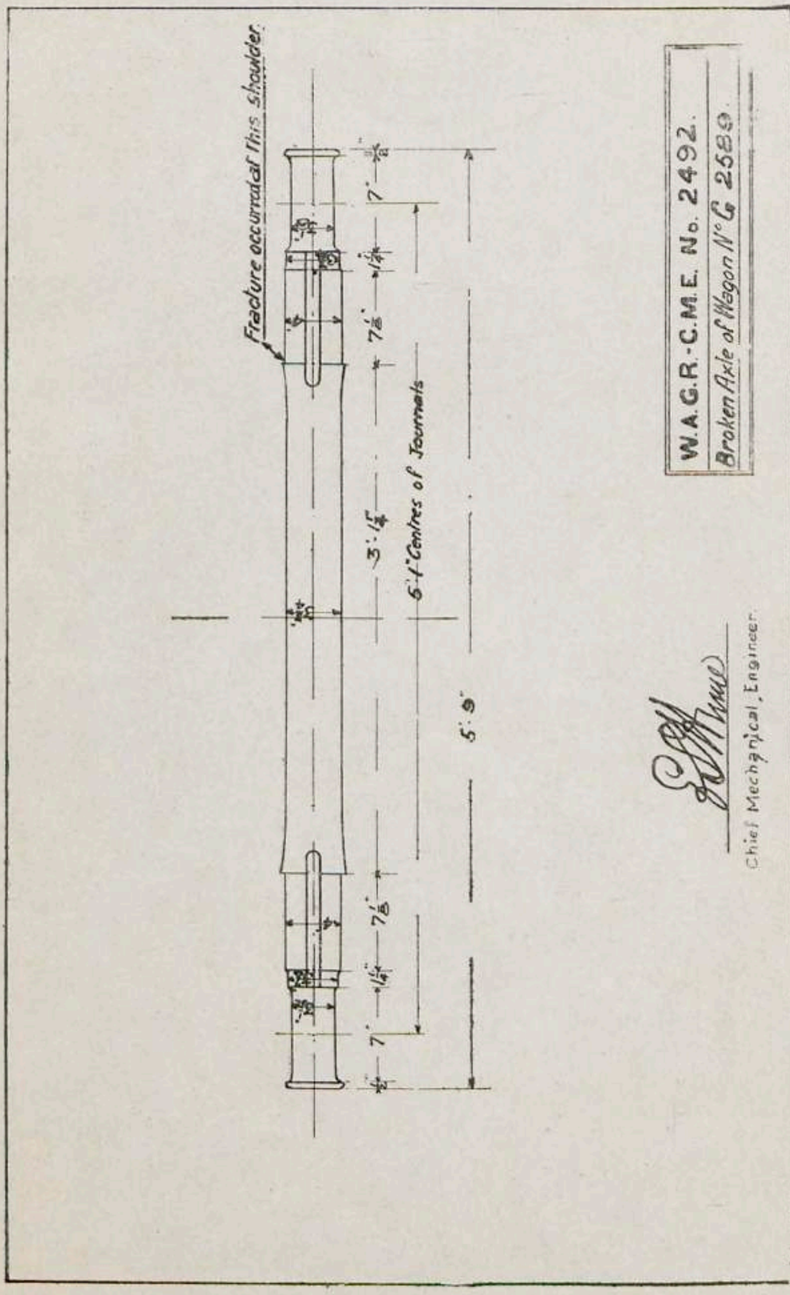
Carrying Capacity		System of Lighting	Brake	Tara			No. in Service						
1st	2nd			T.	C.	Q.	30/6/06	30/6/07	30/6/08	30/6/09	30/6/10	30/6/11	30/6/12
6	12.	Oil	Trainpipe	4.	5.	0.	4	3	2	2	4	4	3

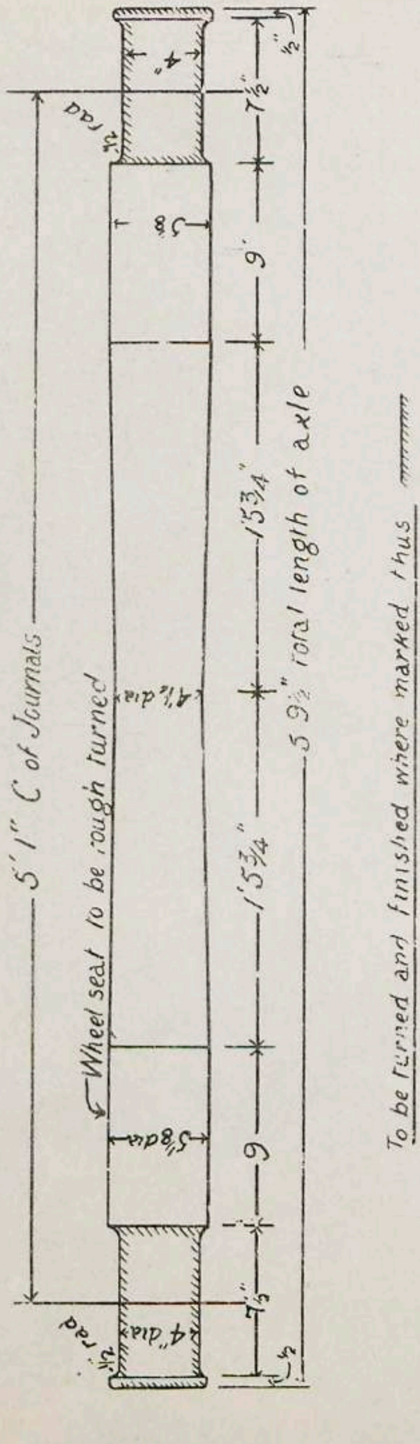
16.


WAGR
2nd Class Suburban Car Class A T
Second Class Compartments
58' 0"
No in Service
30

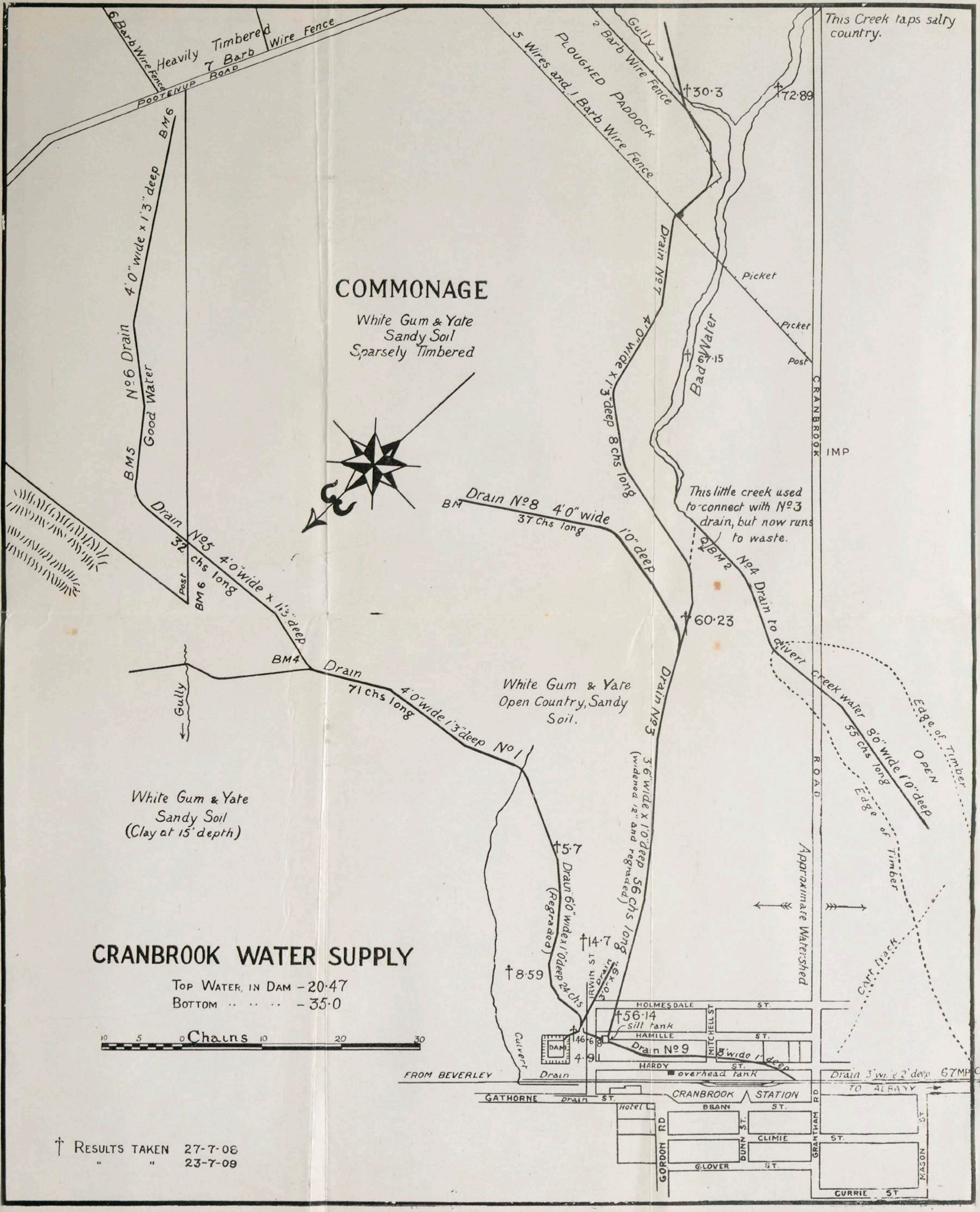

WAGR
1st Class Corridor Car. Class AQ
Four Berth Compartments
Two Berth Compartments
Corridor
Ladies Lavatory
Gent's Lavatory
58' 0"
40' 0"
25.


W.A.G.R
Dining Car Class AV
DINING CAR
Dining Saloon
Kitchen
Corridor
Store
Table
Sinks
60' 4" over Buffers
58' 0"
Brake
Tare
No in Service
Electric
Vacuum
24
32.


W.A.G.R.-C.M.E. No. 2492.
Broken Axle of Wagon No G 2589.
Fracture occurred at this shoulder.
5' 1" Centres of Journals
5' 9"
Chief Mechanical Engineer.

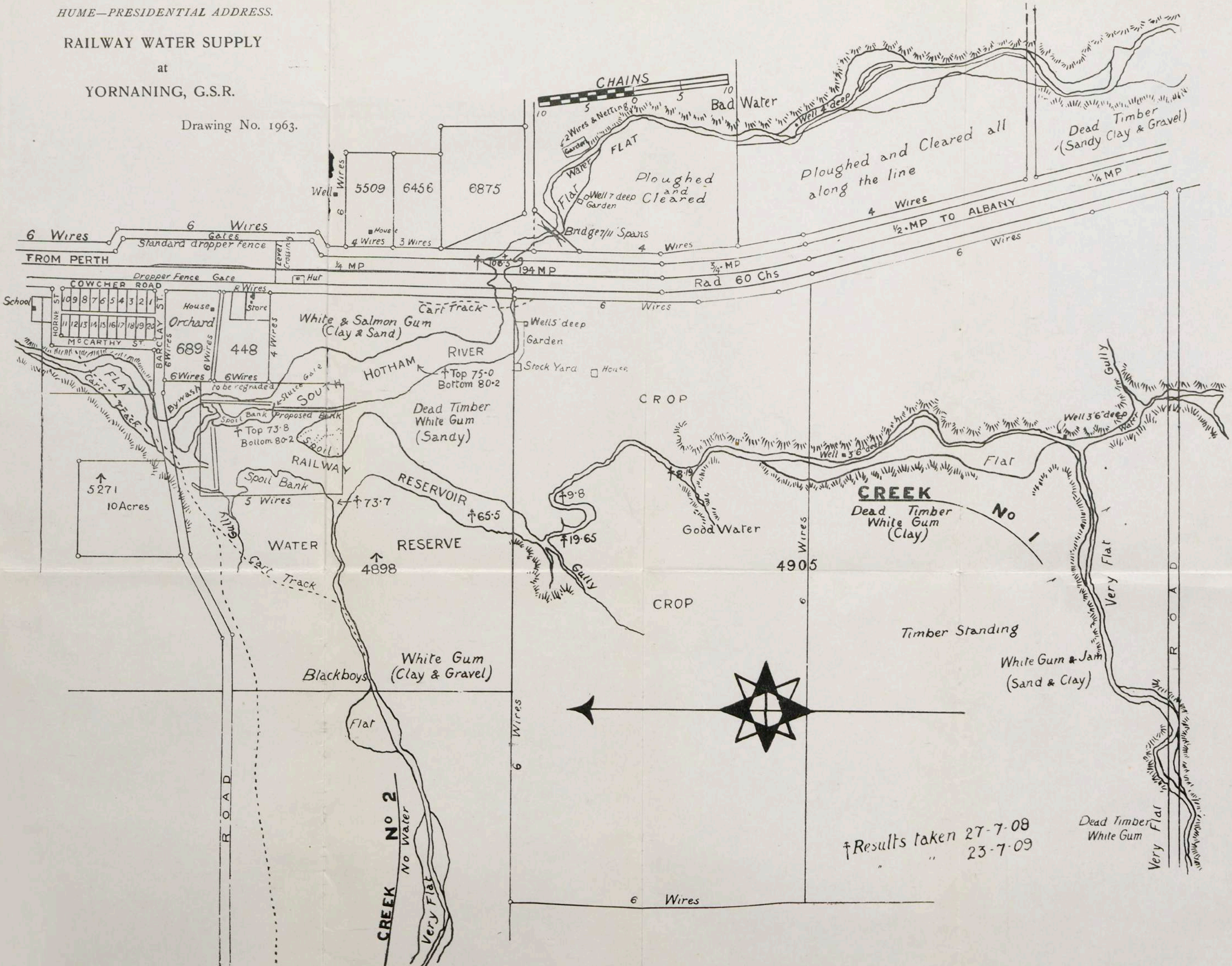


Standard Carriage and Wagon Axle.


CRANBROOK WATER SUPPLY
Top Water in Dam – 20·47
Bottom .. .. .. – 35·0
Chains
† Results taken 27-7-08
" " 23-7-09
COMMONAGE
White Gum & Yate
Sandy Soil
Sparsely Timbered
White Gum & Yate
Open Country, Sandy Soil.
White Gum & Yate
Sandy Soil
(Clay at 15' depth)
Heavily Timbered
7 Barb Wire Fence
6 Barb Wire Fence
Pootenup Road
Ploughed Paddock
2 Barb Wire Fence
5 Wires and 1 Barb Wire Fence
Gully
This Creek taps salty country.
Drain No 6 4'0" wide x 1'3" deep
Good Water
BM6
BM5
Post
Drain No 5 32 chs long 4'0" wide x 1'3" deep
BM4
Drain 71 chs long 4'0" wide 1'3" deep No 1
Drain No 7 4'0" wide x 1'3" deep 8 chs long
Bad Water
Drain No 8 4'0" wide 37 chs long 1'0" deep
BM
This little creek used to connect with No 3 drain, but now runs to waste.
BM2
No 4 Drain to culvert creek water 8'0" wide 1'0" deep 55 chs long
Drain No 3 3'6" wide x 1'0" deep 56 chs long (widened 12" and regraded)
Drain 6'0" wide x 1'0" deep 24 chs (Regraded)
Edge of Timber
Open
Approximate Watershed
Cranbrook Road
IMP
Picket
Post
Cart track
†30·3
72·89
†67·15
†60·23
†5·7
†14·7
†8·59
†56·14
46·6
4·9
Sill tank
Dam
Culvert
Drain No 9
3' wide 1' deep
Irwin St
3'0" x 9" drain
Holmesdale St.
Hamille St.
Hardy St.
Mitchell St.
overhead tank
From Beverley
Drain
Gathorne Drain St.
Cranbrook Station
Drain 3' wide 2' deep
67MP
To Albany
Hotel
Gordon Rd
Bbann St.
Dunn St.
Clime St.
Glover St.
Grantham Rd
Mason St.
Currie St

RAILWAY WATER SUPPLY
at
YORNANING, G.S.R.

Drawing No. 1963.



INVESTIGATIONS OF MICROSTRUCTURE IN CERTAIN METALS AND ALLOYS.

(By Professor A. D. Ross.)

During the past few years there is perhaps no branch of the science of metallurgy which has received more attention, aroused greater and more widespread interest, and yielded more valuable results from specialised investigation than metallography. Metallography may be defined as the study of the internal structure of metals and alloys, and of its relation to their composition and physical and mechanical properties. It is a branch of physical chemistry and is intimately connected with crystallography. Regarded from the standpoint of a science, metallography formulates various theories for the many phases of structures existent in metals and their alloys, and serves to explain the somewhat complex changes which occur as metal passes through the several stages of solidification or subsequent heat treatment, which may or may not be accompanied by mechanical treatment. But, just as practical metallurgy may be looked upon as an art—the art of extracting metals from their ores on a successful commercial basis—so practical metallography may be considered as an art also—the art of treating the finished metal in such a way as to make it reveal its internal structure, and, further, of interpreting its appearance as revealed in a microscopic examination so as to arrive at a fairly accurate idea of its life history and fitness for any particular engineering purpose.

In practice, therefore, metallography has been found to be a valuable aid to methods of proximate analysis, since by its aid many prevalent ideas as to the structure of materials have been revolutionised. At the outset, however, it must be confessed that without the aid of the chemist the metallographist would very often be quite at a loss, because analysis detects certain definite constituents while the microscope is able only to locate them. Further, its field of usefulness is strictly limited to the detection of variations in the physical structure, for the microscope can give no indication of the presence of combined or dissolved impurities unless these give rise to differences of structure or coloration on suitable treatment. Very little value can be attached to the structure of pure metals, which may indeed be highly crystalline, but not evince the true crystal form on account of mutual interference in the growth of the crystal grains during solidification. No more are definite chemical compounds or solid solutions of one metal in another capable of being resolved microscopically, and no structure can be observed other than that due to crystallisation. It does not follow that the presence of the alloying metal or metalloid may not alter the whole structure,

making it quite distinguishable from the pure metal, but simply that its separate constituents cannot be rendered visible. Most alloys are, however, of comparatively complex structure, since, as solidification goes on, one constituent (usually a solid solution) separates or freezes out gradually, leaving the molten portion enriched in a second constituent which finally solidifies in the interstices of the primary crystallites in the form of a entectic or solidified mother liquor which has the lowest melting point. (See Plate I, fig. 1.) The entectic is not a chemical compound, but is itself a mixture of two constituents which may be chemical compounds, and these in the normal condition are usually arranged in more or less parallel plates.

Whilst there are several sub-divisions of metallography dealing with mechanical characteristics and thermal treatment, I think that one of the most useful branches in the arts is probably the pathological study which concerns itself chiefly with the diseases of metals, such as incorrect treatment or the presence of deleterious impurities. In most text-books on the subject of metallography one finds ample information regarding the structures of iron and steel and many other alloys which have passed through normal or even ideal conditions. These present standards for useful comparison, but as a rule very little is said on the subject of inferior metals and on the appearance under the microscope of metal which has serious inherent defects. I therefore propose to consider, among other things in this lecture, a few examples which have come under my notice of "something gone wrong" in metals—cases of defects which the chemist would be unable to fathom but which are readily discernible by a very simple microscopic examination.

The proper selection and preparation of a sample or section for microscopic examination is of the utmost importance, especially in the case of investigating the cause of a failure. Wherever possible, the actual fracture should be carefully preserved to prevent the disguishing influences of dirt and rust, and not only should cuts be taken from the metal at the point of fracture, but also at a short distance from it, for the sake of comparison. The samples are then polished until the surface is perfectly smooth and practically free from scratches. For this purpose a polishing machine is used, the rotating disc of which is covered with paper or cloth carrying the abrasive material. Successively finer grades are employed in the process, and, by always changing the direction of polishing at each step, the unaided eye can readily discern when all the former scratches have been removed. The attrition should never be so heavy as to make the surface flow by partially melting or to heat the metal up to such a temperature as to bring about structural change of the constituents. The final polishing is usually accomplished wet by means of a

selvyt cloth moistened with water carrying a small quantity of diamantine or levigated alumina powder in suspension. After carefully drying the specimen in alcohol or ether, one examines the specimen at this stage under a low power microscope to see whether it is perfectly polished and to all intents free from scratches and also to make out any irregularities in the metal itself.

In some cases a metal or alloy treated in this way may be at once subjected to microscopic examination, but in the great majority of cases it is necessary to "develop" the structure, or rather to differentiate its various parts in some convenient way, such as by etching with a reagent which attacks the surface or discolors certain portions, leaving others bright and little affected. Among the most useful etching liquids are the following :—(i) A saturate alcoholic solution of picric acid ; (ii) nitric acid, concentrated, dilute, or in solution in mixed alcohols with acetic anhydride ; (iii) ammonia, diluted to 1 part with 3 of water ; (iv) ferric chloride, a syrupy solution being added to strong hydrochloric acid and then diluted ; (v) hydrochloric acid, concentrated and dilute. The necessity for etching is also partly due to the occurrence of a surface flow in the metal during polishing. Flow takes place to a great extent on soft substances, and to an appreciable, if small, extent on the surfaces of even the hardest crystalline substances. Beilby was the first to demonstrate the existence on polished surfaces of a thin layer of flowed structureless material strongly resembling in its behaviour a highly viscous fluid. The "forced polish" produced by burnishing is due to the formation of a deep layer of this flowed material. Its formation is well shown on the surface of a hard manganese steel where polishing soon partially fills up any scratches on the surface. The scratches are again in evidence when the surface is etched with a one per cent. solution of nitric acid in alcohol.

While the crystallisation of solid components from molten alloys and of salts from solutions are processes of essentially similar nature, there is, as a rule, a noteworthy difference in the manner of growth of the crystals. On deposition from a solution salts generally form more or less perfect crystals bounded by plane faces, and these crystals grow in all directions so that they retain their original shape and proportions. Metals and alloys, on the contrary, form first of all small crystalline nuclei which grow almost exclusively in the direction of certain axes giving rise to elongated and much branched formations, the "crystallites" or "crystal skeletons." Even under the most favorable conditions of cooling, there is little growth of the crystal faces, and the final forms frequently exhibit highly curved crystal faces. Arborescent or dendritic structures are therefore common in metals and alloys. Lehmann* has made a very complete study

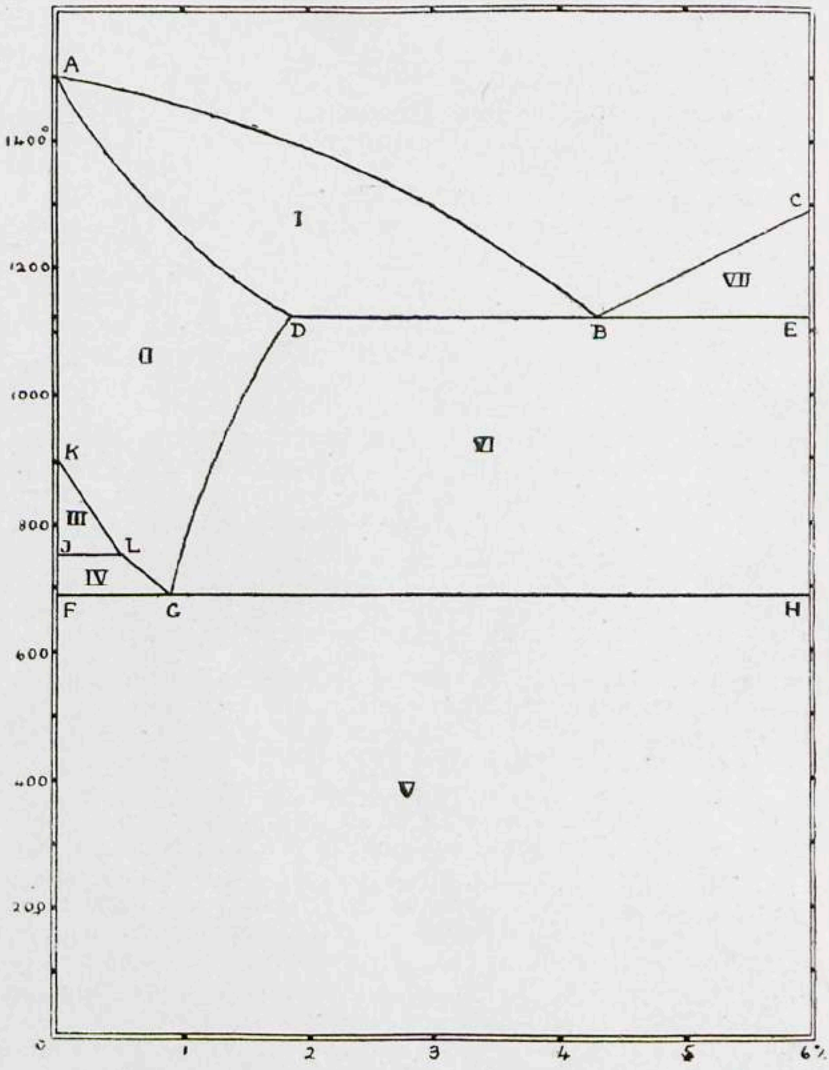
* O. Lehmann, *Molekularphysik*, vol. 1, Leipsig, 1888.

of the growth of crystals. He has shown that diffusion is greatest at the most sharply pointed angles of the crystal. Now, crystals can grow only in a supersaturated solution. As soon as the liquid layer in contact with the crystal ceases to be supersaturated deposition ceases, and the growth of the crystal can recommence only after diffusion has again increased the concentration of the adjoining layer. Consequently metallic crystallites develop axially, and continue to do so until progress is impeded by matter belonging to other crystallisation centres. The process of solidification is thereafter a gradual filling up of the interaxial spaces. The final solid body is thus built up of polyhedra (see Plate I, figs. 4 and 5), one originating from each centre of crystallisation, and as the orinetation of the axes of neighboring crystallites varies in a chance manner, the polyhedra vary in shape and size.

In the case of the crystallisation of salts from aqueous solution, the size of the resultant crystals depends on the slowness of the process. So in the case of metals, slow cooling results in the formation of large crystals, and rapid cooling gives smaller crystals. This can be well shown by comparing the appearances of microphotographs of sand and chill castings of the same material. (See Plate I, figs. 2 and 3.) Even after a metal has been cast, it is in many cases easily possible to completely change the crystalline structure by heating to a temperature far below the melting point of the material. Prolonged annealing of a metal at a moderately high temperature is thereafter apt to cause an undue growth of the crystals, and the metal may thus be seriously impaired in strength owing to the development of a coarse structure.

The effect of heat treatment on metals is of the very highest importance. Varying heat treatment, while it need not—and generally should not—affect the chemical composition, will as a rule materially alter the mechanical and other physical properties. Thus such alloys as definite iron-carbon alloys, copper-tin or copper-aluminium alloys, assume different stable conditions according to the existing temperature. If slowly cooled from near the melting point to ordinary temperature they have a known stable constitution. But when at a high temperature the constitution is totally different, the phases then present being stable at that temperature, but, in general, unstable under ordinary conditions. It is, however, possible to preserve the constitution which is stable at the high temperature by cooling the metal under proper conditions. If the hot metal is rapidly quenched in ice-cold water, the structure corresponding to the high temperature is more or less "fixed" by the process, and the phases are said to be present in a metastable form. Equilibrium diagrams, as they are called, have now been constructed for all

important binary alloys, and these show the constituents present in any alloy in the series under varying conditions of temperature.



The figure shows part of the rather complex equilibrium diagram of the iron-carbon alloys. The percentage of carbon in the alloy is indicated by the figures along the bottom of the diagram, and the figures up the left-handside indicate temperatures. The curve *ABC* gives the temperature at which the various alloys become completely liquid, and curve *ADBE* gives the temperatures at which complete solidification is attained on

cooling. The other horizontal and inclined lines represent changes in the constitution of the solid alloys. The constituents present in the seven different compartments (I to VII) are as follows :—

I. Austenite Liquid.
II. Austenite.
III. Beta-iron Austenite.
IV. Alpha-iron Austenite.
V. Alpha-iron Cementite.
VI. Austenite Cementite.
VII. Cementite Liquid.

Accordingly, an alloy containing say 0.3 per cent. carbon will undergo several changes in solidifying and cooling slowly to ordinary temperature. Part of the melt will solidify at about 1,500° C., and soon after solidification will be complete, the whole mass consisting of austenite—that is of a solid solution of carbon in gamma iron. On cooling to 820° there is a change in constitution and the metal now consists partly of beta-iron and partly of austenite. At 760° another change takes place—the beta-iron alters to alpha-iron and the steel becomes magnetic. Finally, at about 690° or 695°, the constituents are transformed into a mixture of alpha-iron and cementite (the carbide of iron). All these changes are marked by changes in mechanical and other properties, for beta-iron is harder than gamma-iron or alpha-iron, and alpha-iron alone exhibits characteristic magnetic properties.

For certain purposes it may be desirable to have in a metal at ordinary temperature some constituent which is stable only at high temperatures. Thus, since austenite is a hard constituent it is frequenty desirable to have it present in a metastable condition in cold steel. This, as will be seen from the figure, is easily attained by quenching the metal at a temperature of about 900° C On the other hand, if it is undesirable to have this constituent in a sample of steel, and there is a possibility of its being present through the metal having been suddenly chilled in manufacture, we can readily remove it by heating the metal to redness and slowly cooling it back to room temperature. The austenite is then decomposed and a mixture obtained of alpha-iron and carbide of iron (cementite). A study of the equilibrium diagram of a system of alloys accordingly affords the information necessary for a rational application of heat treatment. It is to be remembered, however, that quenching is never sufficiently sudden as to be "ideal" in its power to fix or stereotype structure. In all practical cases there will be a more or less apparent change towards the constitution which is stable at room temperature. Thus no quenching will in practice be sufficiently powerful to prevent the decomposition of austenite : a steel at ordinary temperature can never be formed of pure austenite.

The general method of investigating a failure in metal is to subject the material first to chemical analysis to determine faults due to incorrect composition or segregation of impurities, then to mechanical tests to show up defects arising from incorrect working of the material, and finally to examine sections with the microscope to see if the metal has been subjected to incorrect heat treatment or to fatigue. Each of these methods affords valuable evidence, but it is only by drawing conclusions from the combined results that we can hope to get near the true solution of the problem.

Only rarely is deliberate fraud tried in the doctoring of defective material, and in this case, even if the first two methods are insufficient, then the microscope is of the utmost service. Heat treatment of a cast-on test bar can be immediately detected, and such an unusual expedient as casting in a piece of another material to give better results on testing is very easily found out. A rather remarkable case of such deception came under my notice in connection with a consignment of Swedish charcoal iron which gave astonishingly good tensile tests. Analysis showed nothing abnormal as regards slag or carbon content, but a micrograph of a cross section at once revealed alternate piling of wrought iron and mild steel in the bar for rolling!

Many failures are to be ascribed to improper heat treatment. A very interesting case of failure, and one which might easily have been attended with highly disastrous results, was the breaking of an express locomotive axle on one of the Scottish railways a few years ago. The design of the axle was doubtless faulty, and, in addition to its having been run considerably over its normal distance, the material was in a condition liable to succumb to fatigue. Plate I, fig. 4, shows the metal—a medium carbon steel—to have been left in a " raw " or overheated condition, with the characteristic lattice structure. This is decidedly brittle and weak in character. Had the metal been in proper form its appearance would have been somewhat similar to that shown in Plate I, fig. 6. The acicular structure, as it is called, should have been replaced by a fine-grained mixture of alpha-iron and cementite. Plate I, figs. 5 and 6, illustrate the effect of annealing a brittle motor-car axle. The metal was supplied as in fig. 5 and failed before 100 miles had been covered. The metal was in a weak and brittle condition due to improper cooling after forging. Annealing decomposed the hard polygona grains of austenite and left (as shown in fig. 6) a finely granular mass of pearlite and white patches of cementite, the pearlite being the entectoid mixture of alpha-iron and carbide of iron.

Plate II shows another not uncommon cause of failure produced by improper heat treatment. The material was a steel containing about 2.6 per cent. of manganese, and nominally

about .7 per cent. of carbon. The metal had, however, been kept for a long time at a high temperature in the process of annealing, with the result that the carbon in the surface layers had been to a very considerable extent " burnt out " by the oxidising action of the air. This at once is evident from the marked change in structure of the material towards the edge of the cross-section.

Segregation of certain constituents (often impurities) in metals is a common origin of fractures. It is in dealing with such cases that a microscopic examination is of the greatest value, for a chemical analysis will afford only an average for a portion of the metal and will give no indication as to the evenness of distribution of the constituents throughout the sample.

The fatigue of metals is a very peculiar phenomenon, due to what is erroneously described as the effect of crystallisation. As a matter of fact, a microscopic examination of fractured metal shows that the structure has not become coarser, that there is no real increase in the size of the crystal grains, but that the brilliant facets on the fractured surface are merely cleavage planes. In short, fatigue of a metal is nothing more nor less than the breaking down of the crystalline formation. If a piece of metal with a smooth polished surface is bent or stretched, a number of fine lines make their appearance under the microscope, running parallel to each other over the area of a single grain, but generally varying in direction from one grain to another. These lines are not cracks, but ridges, and are known technically as " slip-bands." They are due to the fact that the regular orientation of the particles in a crystal allows slipping of the particles to occur more readily in certain directions than in others, giving rise to " gliding-planes." The phenomenon is perfectly analogous to repeated faults or " step-faults " in geological strata. Thus by a rapid series of alternating stresses which are well within the elastic limit it is possible to speedily break down a metal by causing the growth of a large number of slip bands in the crystal formation. These rapidly spread by extension along the cleavage planes of the crystals, following the line of least resistance, and, communicating themselves from crystal to crystal in the same direction, make the fracture eventually produced exhibit a series of very large crystal faces. The cure for fatigue in metal is therefore to check it early by an annealing at say 750° C. for ten to fifteen minutes. But if the crack has already commenced, annealing will only enhance the fault by forming oxide films on the exposed surfaces of the crack, thus embrittling the structure.

I have already referred to the effect of quenching at high temperatures in retaining in a metastable state at ordinary temperatures the beta and gamma types of iron which correspond to high temperatures in the metal. The addition of nickel,

manganese, chromium, and certain other elements has a similar effect, and the remarkable toughness of Hadfield's manganese steel (12 to 13 per cent. manganese, and about 1 per cent. carbon) is to be ascribed to this action. The author has found from magnetic tests that the addition of even 2 per cent. of manganese has a marked influence. When the proportion is raised to 6 per cent. the manganese prevents the gamma-iron undergoing transformation into alpha-iron on cooling the metal from a red heat, and so the steel is practically non-magnetic. If, however, it be immersed in liquid air at a temperature of 190° below zero centigrade, the manganese is then unable to overcome the greater tendency for a transformation and the steel acquires magnetic properties. Plate III, fig. 1, shows a 6.5 per cent. manganese steel which has been annealed at a temperature of about 850°. The chief feature is the interlaced structure of accicular or "martensitic" constituents which consist of non-magnetic gamma-iron. The white groundmass is partly the manganese-carbide with any free gamma-iron. Plate III, fig. 2, shows the same specimen after immersion in liquid air. A decided transformation has taken place. The white patches are almost completely freed alpha-iron (magnetic), while the main groundmass is the double carbide of manganese and iron $(Mn\ Fe)_3 \cdot C$, with some partially decomposed martensitic needles.

These notes will, I trust, help to show that the microscopic examination of metals is a study of the highest importance to the engineer, insomuch as it affords the most valuable information on the alloying and thermal treatment of the materials which he has to employ. Its use too in dealing with cases of failures is invaluable in giving hints towards that prevention which is better than cure.

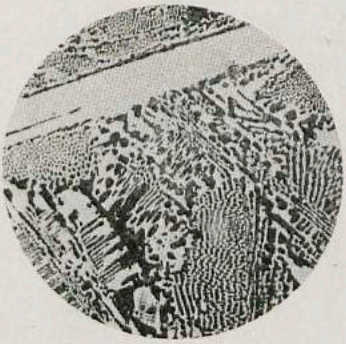


FIG. 1.—Steel containing 4.9 % Mn, 4.4 % C; showing cementite crystals and entectic. (× 100)

FIG. 2.—Copper 86.6 %, manganese 4.8 %, aluminium 8.6 %. Chill cast (× 200)

FIG 3.—Same Cu-Mn-Al alloy. Sand cast (× 200)

FIG 4.—Fractured locomotive axle. (× 150)

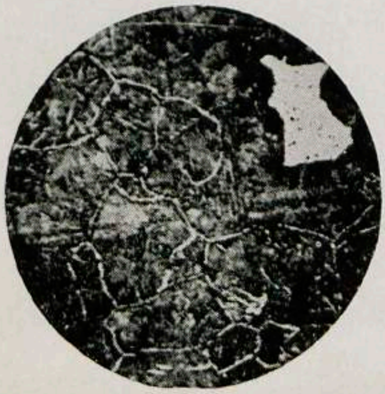


FIG. 5.—Fractured motor-car axle. (× 400)

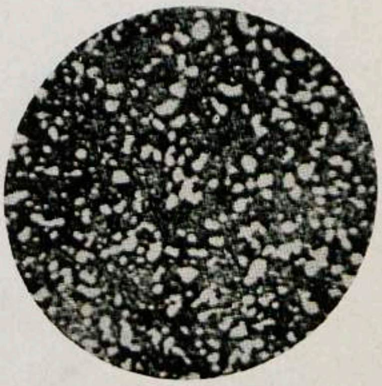
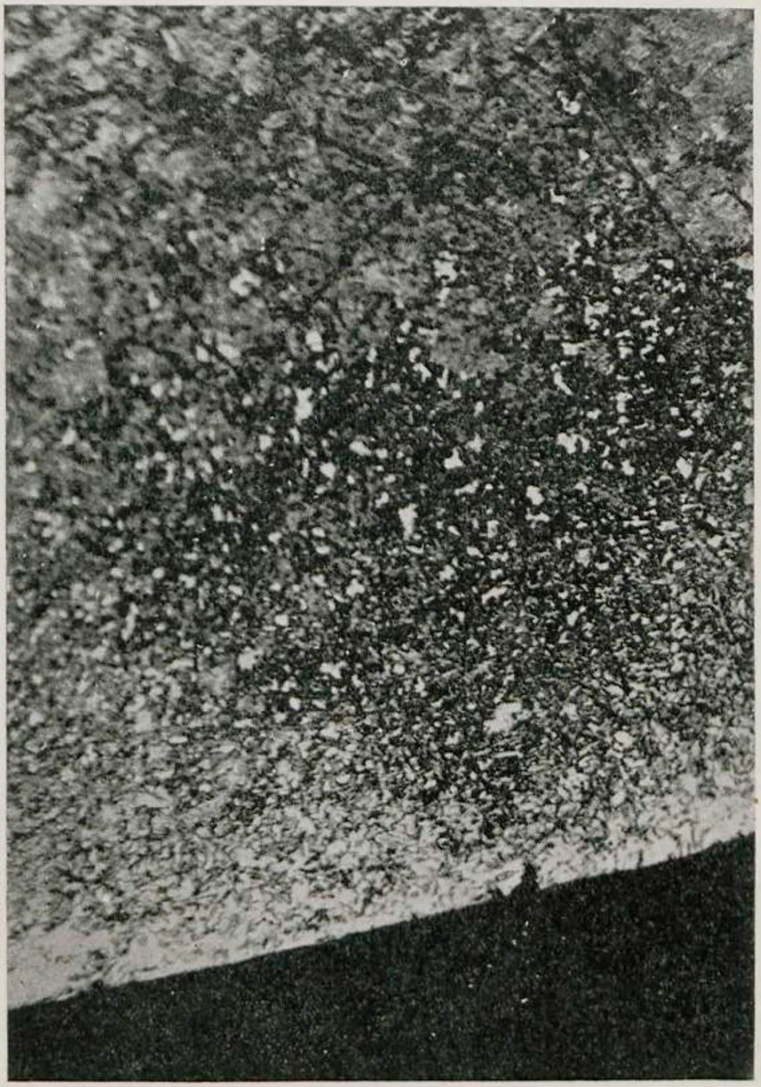


FIG. 6.—Same metal annealed. (× 400)



Manganese Steel Rod showing "burning out" of the carbon by prolonged annealing at a high temperature. (× 300)

FIG. 1.—6.5% Manganese Steel, annealed, showing martensitic structure.
(× 250)

FIG 2.—Same material after immersion in liquid air, showing transformation to alpha-iron.
(× 250)

THE NORTH-WEST HARBORS OF WESTERN AUSTRALIA.*

(By W. H. Young.)

The State of Western Australia, with its enormous area and extensive coast line, possesses a very great number of harbors, all practically developed and controlled by the State Government. These harbors are in every stage of development, from a first-class harbor like Fremantle, capable of berthing any steamer passing through the Suez Canal, down to ports where the only accommodation is a small boat jetty on the open beach.

The history of many of these harbors is interesting reading from an engineer's point of view. It would not, however, be possible to deal with more than one or two, at most, of the major ports in the course of a single evening. I propose to-night to traverse that length of our coast line extending from Shark's Bay to King Sound, and give as well as I am able the history of the growth of the various ports which are growing up at intervals along that portion of the coast.

In order to begin at the beginning of the subject it is necessary to briefly outline the history of that portion of the State. I would like to acknowledge my indebtedness in this regard to the Hon. A. R. Richardson, from whose interesting book, "The Great Nor'-West," I have drawn the materials for the historical portion of this paper.

Somewhere in the early seventies pastoralists took up country in the vicinity of Roebourne and founded stations. The only means of communication for some years was by schooner with Perth, and owing to the inefficiency of this method there was a very little prospect of development. Fortunately, however, it was discovered that mother of pearl abounded on the reefs along the shore, and many of the station holders took up pearling, with great benefit financially. Eventually pearling developed into a separate industry, with Broome as its headquarters.

From Roebourne settlement extended north and south until the whole of the country was taken up. Further assistance to settlement has from time to time been given by the discovery of gold at various places, notably the Kimberley rush of the early eighties, and later the Marble Bar boom. As settlement increased the means of transport were improved. First a small coasting steamer was put on to run from Fremantle, drawing about twelve feet.

The development of the wool export led to a sailing ship coming direct from England to Condon for wool. This boat used to lie aground in shallow water and at low tide the wool was

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*For plans, see end of paper.

carted out on waggons and put aboard. Further developments led to two English companies instituting a joint fortnightly service between Singapore and Fremantle, calling *en route* at all ports between Broome and Fremantle. The Adelaide Company were also very early in the field, and have for many years now maintained a monthly service from Fremantle.

Quite recently the State has placed a steamer in the trade with the object of giving increased accommodation, lowering charges and generally assisting settlers in their arduous work. This regular fortnightly service was instituted in the early nineties, corresponding with the beginning of the Coolgardie gold boom, which gave such an impetus to every department of industry in this State. These boats had a draft of 20 ft. and accommodation was provided or increased accordingly at each port. This work entailed a large expenditure at each port that is comparatively large.

Having now dealt briefly with the history generally of settlement and development, I will now proceed to give a detailed account of each port from a harbor engineer's point of view.

CARNARVON.

Range of Tides: Springs 5 ft., Neaps 2 ft.

The first boats to trade up this coast from Fremantle were small schooners. Sufficient harbor accommodation for these craft was provided by the mouth of the Gascoyne River, and at a point where deep water occurred close to a high bank it was found possible to land goods round this point, and thus the first beginnings of a town arose. As business increased a small wharf was constructed and goods shed erected. Vested interests now arose round this point and the subsequent development of the harbor has been materially affected thereby. A second stage was reached when a small steamer was placed in this trade. For this boat a jetty was required giving a depth of 12 ft. at low water. A jetty was erected running out to the two fathom line at Teggs Channel. The weakness of this scheme lay in the fact that owing to its position it did not lend itself to an extension into deep water. Later developments brought a fleet of steamers on the coast drawing 16 and 18 ft. of water. To accommodate these search was made for a jetty giving prospects of further extension. A good site giving the necessary depth fairly close to shore, also giving prospects of an easy extension later on to 30 ft., was located at Pelican Hill. As, however, the site was 20 miles north of Carnarvon, it was abandoned for a site nearer the town. This jetty, which is the one now in use, was constructed in 1897. It was constructed to strike the three fathom contour at its nearest point to the shore. To connect the jetty with the town it was necessary to build a tramline across Babbage Island, and a bridge across one of the arms of the Gascoyne River.

FUTURE DEVELOPMENT.—Should it become necessary at any future time to provide for boats of deeper draught, recourse will have to be had to either extending the jetty or deepening a channel up to it. The distance from the end of the present jetty to the five-fathom contour line is 3 miles ; consequently, to provide for boats of deeper draught will be a mätter of considerable expense.

SHELTER.—This jetty runs out into practically an open roadstead, sheltered by islands 30 miles away. The climate, however, is of such a mild character that the use of the jetty by steamers is rarely interfered with.

GENERALLY.—Carnarvon is not well situated as a harbor. The whole neighborhood consists of light alluvial deposit. Babbage Island, across which the tramline runs, is particularly so. The town is situated on the outer curve of a bend in the river, and in consequence is in constant danger from the erosion and undermining of the banks.

ONSLOW.

RANGE OF TIDES : Springs 8 ft., Neaps 4 ft.

The town of Onslow is situated about 4 miles from the mouth of the Ashburton River. The location was decided, as at Carnarvon, by a suitable bank on the other side of the river, to enable schooners to berth. Later on a wharf was constructed and goods sheds erected in its vicinity, and coastal lighters were put on to carry goods and passengers ashore. This condition of affairs is still obtaining. For some years the lighters continued to use the old wharf up the river ; but as the river is tidal, a great deal of delay was caused at low water. To obviate this inconvenience a lighter jetty was erected. This jetty is 1,120 ft. long and extended into 8 ft. of water. Steamers anchor at present about a mile from the end of the jetty, to which all goods and passengers are conveyed by lighter. As may be readily understood, this process is tedious, inconvenient and expenisve ; and the progress of the port and district are hampered considerably. A good deal of anxiety is in consequence manifested by those interested in the district to see the jetty extended to the 3-fathom contour. As this would entail construction of a jetty a mile long, and maintaining same, the great expenditure necessary has militated so far against anything being done. The three-fathom line approaches nearer the shore to the west of the mouth of the river, but there are several drawbacks to the construction of a jetty there, such as lack of shelter for small craft during wintry weather, insecurity of approach, and the necessity for building a new approach across the river and the island. In addition to the main entrance to the river there is a small channel connecting with the sea. It is probable that the mouth of the river was situated at this point at one time,and that the land is gradually growing seaward owing partly to deposits brought

down by the river, but more, I think, to sand cast up by the sea. There are many indications I think that the whole western face of this State is slowly advancing seawards. Indications of this fact are to be seen at more than one port on the west coast. (The author here referred to instances of above at Busselton, Bunbury (Estuary), Mandurah (Estuary), Carnarvon up to Minilya, and Onslow.)

DEVELOPMENT TO 30 FT.—It may seem premature in the case of this port to look so far ahead, but indications in this regard are decidedly unfavorable, as the five-fathom contour is about 4 miles from the shore at its nearest point approachable from the sea. The drawbacks to this port from a harbor engineer's point of view are many, and a movement is afoot to search the coast line in the vicinity for a site where more favorable conditions occur.

SHELTER.—This is practically an open roadstead, but during the mild weather experienced during a great part of the year no inconvenience is experienced. During hurricane weather, however, a steamer caught in the vicinity of Onslow would be in great danger owing to the network of reefs and small islands which prevail along the coast line.

TRAMWAY.—A two-foot gauge tramway drawn by horses operates between the jetty and the town, a distance of about 4 miles.

COSSACK.

RANGE OF TIDES: Spring 18 ft., Neaps 12 ft.

It was at the port of Cossack that the settlement of the North-West was begun. The conditions of landing at such a port in the early days must have been full of almost insuperable difficulties. Owing to the great range of tide (18 ft.) high-water mark is three miles away from low-water mark. If a landing be made at high water mark it can only be approached at high water springs and then only for a few hours at a time. The port was fixed at Cossack after trying several other landings. There is a creek called Butcher Inlet, which affords good shelter and sufficient water to float a fair-sized schooner at high water neaps. Cossack, however, is only an island at high water and two costly embankments each over a mile long have had to be constructed to connect it with the mainland, one for a road and the other for a tramway. No fresh water was obtainable at Cossack, and the site for the main township was fixed at the nearest fresh water, which consisted of a large fresh water pool on the Harding River, about eight miles from Cossack. Here the township of Roebourne was built, and for many years it was the principal town north of Geraldton. In 1882 a 2 ft. gauge tramline 8 miles long was constructed between Cossack and

Roebourne, and was worked by horses up till quite recently. The harbor at Butcher Inlet was unable to accommodate steamers and as the cost of dredging it out would be very considerable, nothing was done in that direction. The steamers anchored off Jarman Island, and passengers and cargo were lightered ashore. This arrangement was, of course, most unsatisfactory, and in 1895 Commander Dawson pointed out that there was a site for a steamer jetty at Point Sampson. Owing partly to opposition on the part of the inhabitants of Cossack, the jetty was not built till 1904, and remained without tramway communication with the mainland until 1908. The Point Sampson jetty is open to the north-east, and the late Mr. C. Y. O'Connor was apprehensive lest the jetty should be washed away by a cyclone, as violent gales sometimes occur in this district. To make the jetty safer it was built with a deck level of 15 ft. above high water. As there is 18 ft. of tide here the jetty is 33 ft. above water at low tide. As may be imagined, the appearance is somewhat in the nature of a tower. Jetty work from this point northward is very expensive, as piles 70 ft. long are required: a very expensive length both to purchase and freight. Also in these northern waters the teredo is very much more active than further south. Consequently, piles are sheathed with muntz metal from just below high water to 2 ft. into the ground. All nails and bolts passing through this sheathing must likewise be of muntz metal, otherwise a galvanic action would set up, causing excessive metallic corrosion. Considerable difficulty was experienced in locating a tramline from Point Sampson jetty to the mainland. Point Sampson, like Cossack, is an island at high water, and the tramline does not get free from tidal waters until it has gone six miles from the jetty. Attached plan (No. 1) shows the first route adopted for the tramline, and a subsequent deviation put in about two years ago.

From Point Sampson to Roebourne, a distance of 12 miles, communication is maintained by a 2 ft. gauge tramway operated by two steam locomotives. There is no fresh water to be obtained at Point Sampson, nor between Point Sampson and Roebourne. Consequently it is very unlikely that there will ever be a township at Point Sampson.

FUTURE DEVELOPMENT.—This site does not lend itself to future development, as the five-fathom contour line is a mile and a half out in the open sea. To get a depth of 24 ft. would require an extension of three-quarters of a mile.

PORT HEDLAND.

This is a land-locked harbor, which has a jetty 760 ft. long, having one berth giving 20 ft. at low water springs, connected to 3 ft. 6 in. gauge railway line running 120 miles inland to Marble

Bar. This harbor has no early history, speaking in the sense in which we have dealt with harbors further south. It first came into existence owing to the development of the Marble Bar goldfields. When these goldfields originated their first port was Cossack; later the goods were transhipped at Cossack and lightered to Condon, from whence they were carried inland to Marble Bar. About 1897, however, a small jetty was constructed at Port Hedland, giving one berth of 18 ft.; this was immediately made use of by the steamers trading on the coast, and Port Hedland became the port of the Marble Bar goldfields, and of the extensive pastoral country which has opened up since. Port Hedland as a harbor has many disadvantages: the first of these consists of an outer bar. In order to enable steamers to negotiate this at low water mark a channel over three miles long would have to be dredged, protected, and kept open. Owing to the great range of tide here—24 ft. at springs—the boats are able to cross this bar at high tide during a period of about four days fortnightly. As long as the import trade at Port Hedland amounts only to about 150 tons a week, it can easily be handled by the fortnightly service running at present. Should, however, the trade develop the disadvantage of the outer bar will speedily make itself felt. Inside the harbor there is plenty of deep water; the passage, however, is narrow and tortuous, and, owing to the strong currents induced by the great range of tide, it is difficult for navigation, and it is only on account of the great care exercised, and the local knowledge possessed by the masters of the boats, that the difficulties are safely overcome. The future of Port Hedland as a harbor is best described by saying that it does not lend itself to development on a large scale.

BROOME.

This harbor is completely sheltered on the north-west and west, and is protected on the south-west by a shallow bank. During high water tide, however, there is sufficient water on this bank to enable a considerable sea to get up in the harbor. The history of this harbor is as follows:—The pearling boats first commenced to use a small creek towards the latter seventies, and a small Asiatic town sprang up on the banks of the creek. As trade increased and a jetty became necessary, investigations were made as to the best position, and eventually a jetty was constructed for the use of steamers in 1896. There is one curious feature about this jetty, namely, that it does not extend out to low water mark. To build a jetty on a coast, which stops short of low water mark, seems, to one unaccustomed to such conditions, to be somewhat in the nature of an experiment. The depths of water alongside this jetty are as follows:—

13 ft. at high water neap tides;
23 ft. at high water spring tides,

the range of tides at springs being about 28 ft. It will be seen from this that a boat drawing 18 ft. of water can only berth during about three days and at fortnightly intervals. As long as this condition of things prevails it will be impossible for steamers to call at Broome oftener than once a fortnight. This practically fixes a fortnightly service for the whole coast. The amount of trade at present is such that a fortnightly service can about cope with it, but great inconvenience, expense, and delays are occasioned to people travelling on businses, owing to such a long interval. No doubt, as trade increases, an extension of this jetty will be made, to give 18 ft. high water neaps alongside, thereby ensuring that a steamer can berth during some period of twenty-four hours. Even under these conditions the steamer will be resting on the bottom of the sea during a considerable portion of her stay alongside the jetty, a condition of things that is not at all desirable from the steam ship companies' point of view. After attaining 18 ft. at high water neaps, no doubt a further extension will be in time carried out, to give 18 ft. at low water springs, a depth that will be necessary if it is to be ensured that the steamers will always be floating.

DERBY.

Range of Tides: Springs 36 ft., Neaps 20 ft.

The history of Derby is as follows:—In the early eighties squatters from the Roebourne district in search of more land proceeded north and landed at Roebuck Bay (now Broome). After the land near the coast had been selected, the remaining members pushed on inland and took up land at various places along the Fitzroy River, where there is excellent soil and permanent pools of water. It was felt that a port nearer than Broome was desirable, and a schooner proceeded to investigate King Sound, whilst another party made an exploration on the landward side. About this time a party had been sent from Perth on a small steamer, with the object of founding a township in this vicinity. The landward party discovered at the spot where Derby now stands a prominent point running out into the marshes, and a landing was accordingly made there and the town established. The present jetty was constructed in 1901, and the depths alongside are as follows:—

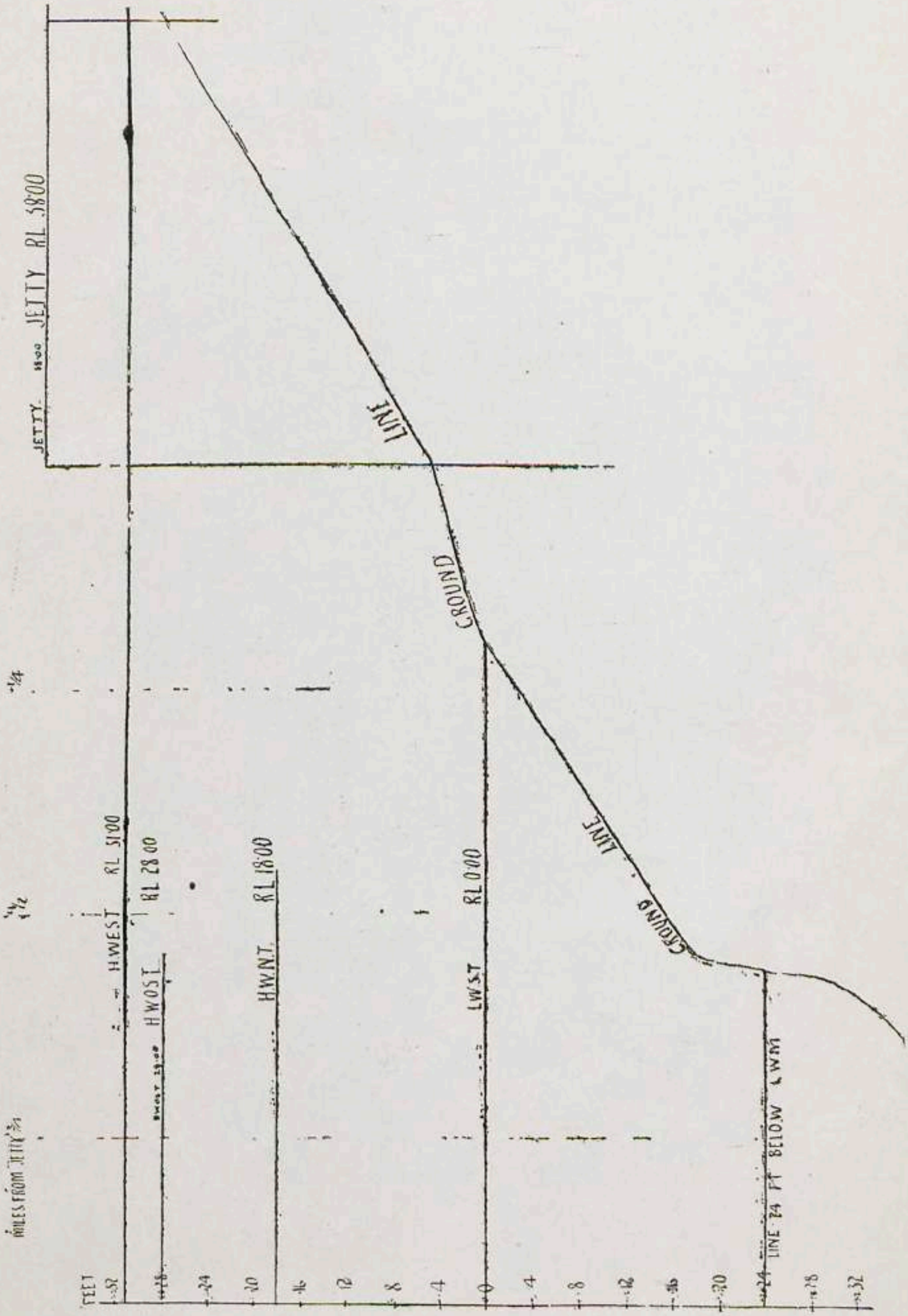
18 ft. at high water neaps,
34 ft. at high water springs.

An interesting phenomenon at Derby is the extreme range of tides, 36 ft. It is, I believe, with the exception of the Bay of Fundy, the highest tide in the world. The jetty here, similarly to Broome, does not extend out to low water. Steamers come up to the jetty at high water and tie up, and are then left high and dry when the tide goes out. At Broome there is deep water close to the jetty within a mile, where a steamer may lie at anchor and

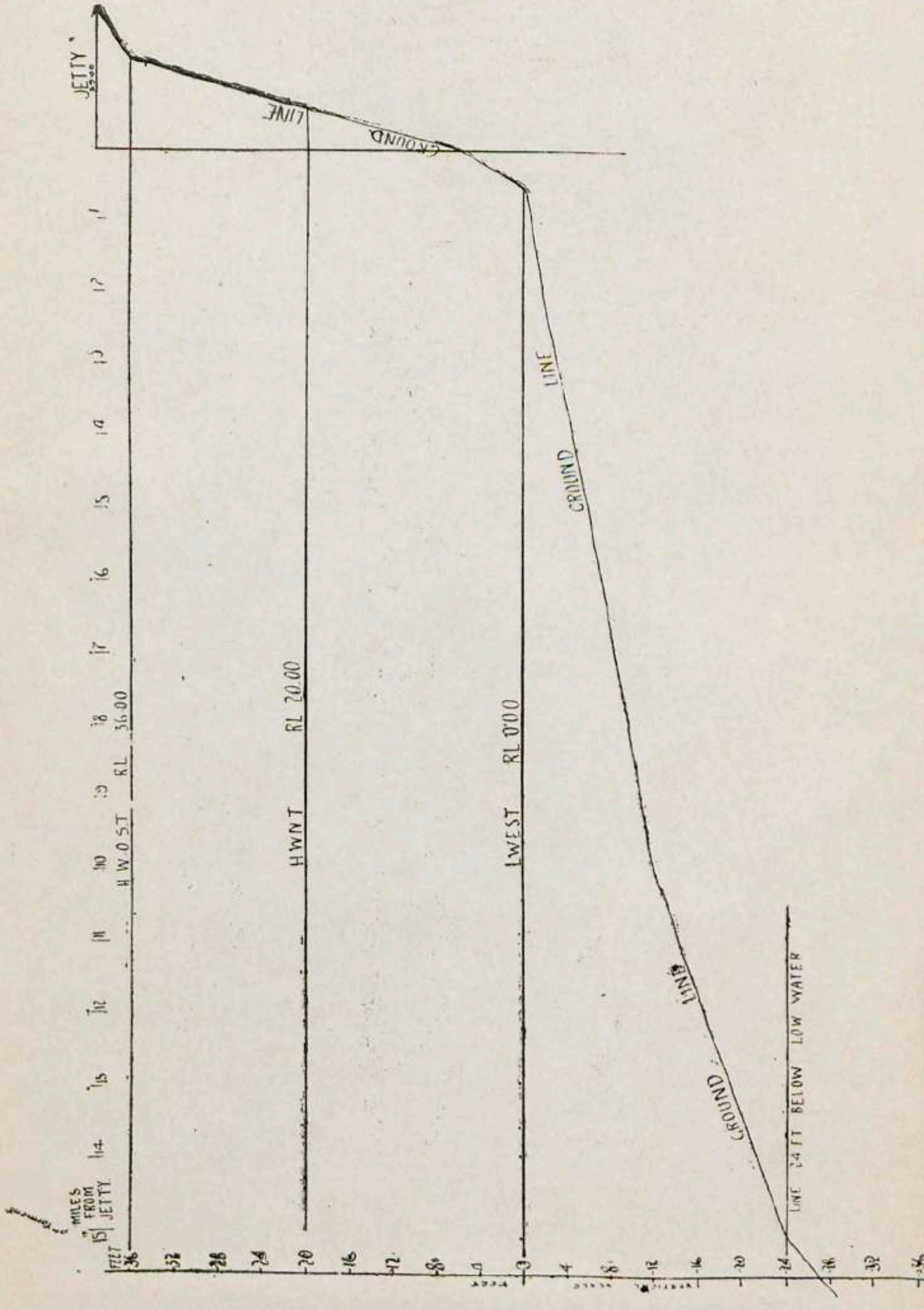
be afloat at low water. This convenience does not exist at Derby. Should a steamer approaching the jetty discover that there is no vacant berth she must turn and steam away for fifteen miles before a position is reached where she may safely anchor. The jetty and approach embankment are over a mile long. There is a 3 ft. 6 in. gauge tramway worked by horses connecting the jetty with the township. A large export trade is done from this port in cattle. As these beasts come in from cattle stations remote from settlement they are exceedingly wild and difficult to handle. The problem of penning, yarding and loading cargo of this nature is a most difficult one. The cattle are driven between wide wings into forcing yards, thence along a narrow race on the jetty through a hinged gangway on board the ship. The design of a suitable gangway took careful consideration, owing to provision having to be made for a universal joint where it was connected to the jetty.

Future Extension.—This jetty does not lend itself to further extension. Should future requirements show a necessity for increased depth the only possibility of doing so would be to move the port north to Point Torment.

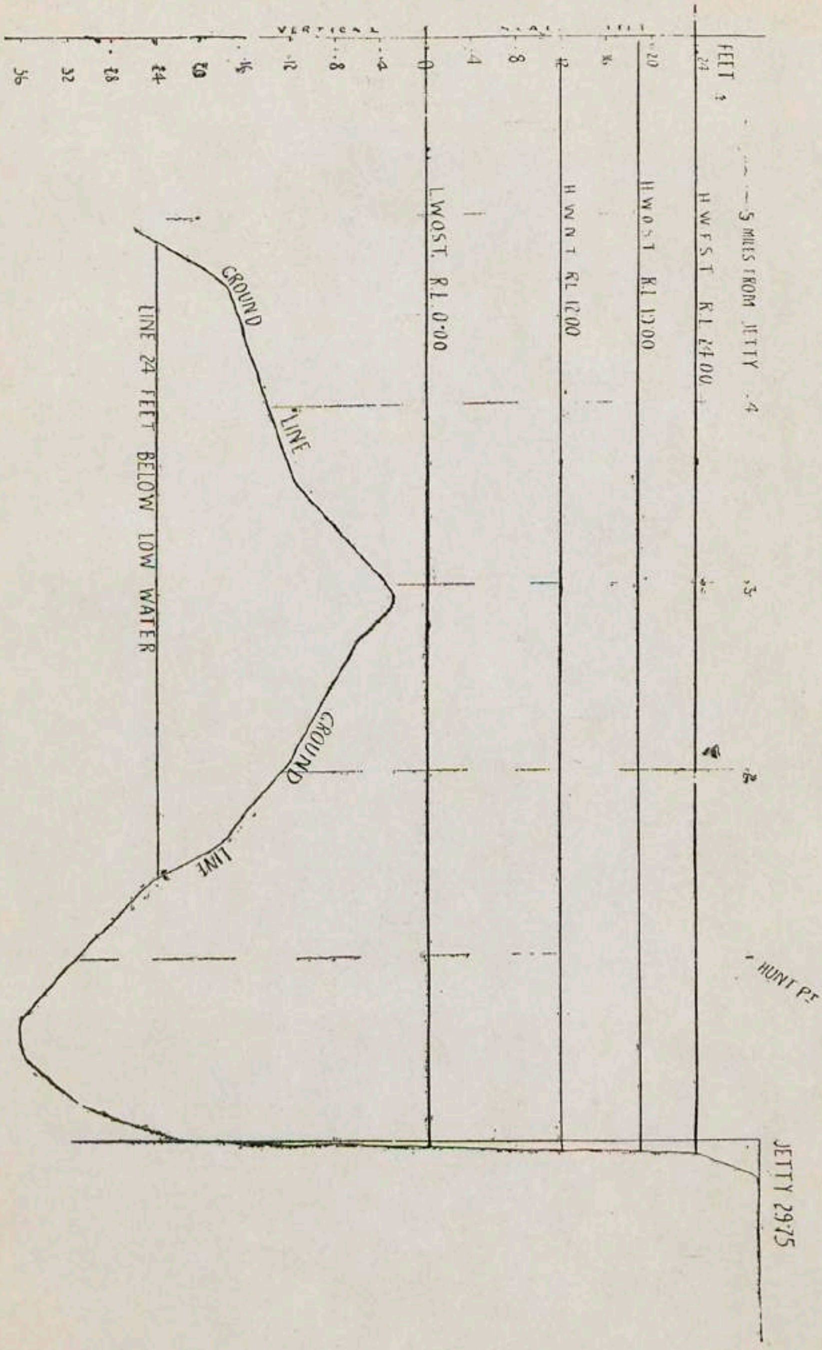
In conclusion, I should like to thank you for the patient hearing you have given this paper. Though only a small portion of our coast line has been traversed, the number of ports dealt with is too many to enable them to be exhaustively treated in a single evening, and I have been compelled to leave out much interesting matter which I would otherwise have been pleased to have included.



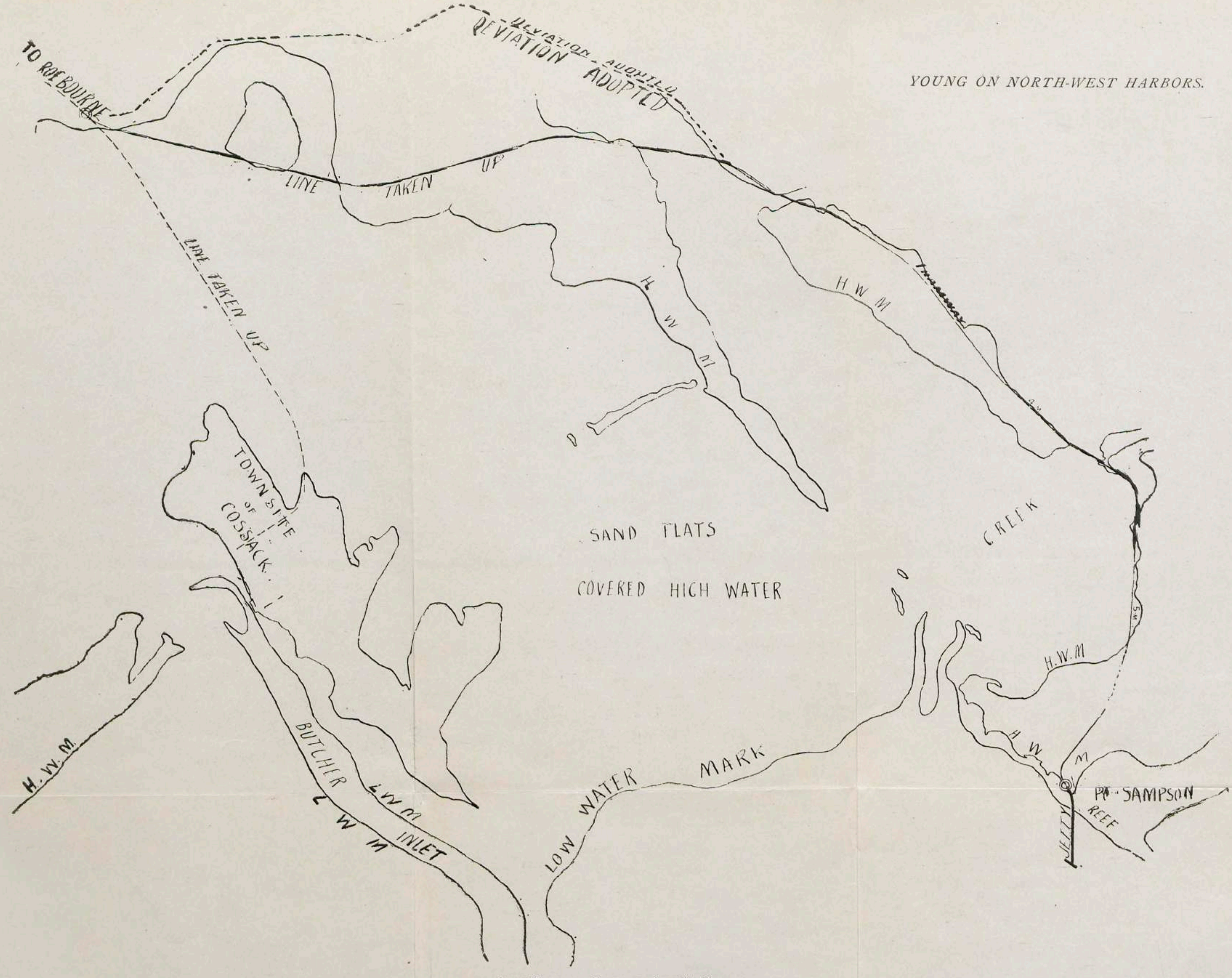
Broome Harbor—Transverse Section.



DERBY HARBOR—Longitudinal Section Jetty to Point Torment.



PORT HEDLAND HARBOR—Section showing Outer Bar.



Point Sampson Tramway—Locality Plan.

SUPERHEATED STEAM IN LOCOMOTIVES.

(By E. A. Evans)

I venture to say that at the present time there is no feature in the working of locomotives offering greater advantages than the superheating of steam. Compounding in its many forms is gradually being superseded by this system in all parts of the world. In Great Britain and the Continents of Europe and America a very large proportion of all the locomotives now being built for their own use are provided with one of the several forms of superheating steam. Some of the States of Australia are also taking advantage of the economy and efficiency to be gained by its use, and in this State we have had it in use for nearly two years. The superheating of steam in stationary and marine boilers has been practised for many years and with pronounced success and freedom from troubles. In these cases, however, the superheat has been confined to much lower temperatures than is now accomplished on the locomotive. The former have contented themselves with a maximum of about 150° above the temperature due to the pressure of saturated steam. In locomotive practice 250° to 300° is aimed at and is readily attained and without insuperable difficulties either in the boiler or the cylinders. In stationary engines under these conditions an economy of 10 to 15 per cent. in coal consumption is obtained, while in locomotives a saving of 15 to 20 per cent. is a figure that is well within the mark. On trials here, spread over four (4) days' running, an economy of 35 per cent. coal and 38 per cent. water was averaged. It is, however, not suggested that such figures could be maintained for a lengthy period. In the case quoted the engines were new and everything working under most favorable conditions.

The first superheated engines to work in this State were of the 4-8-0 type, with 3 ft. 6 in. diameter wheels and cylinders of 19 in. diameter and 23 inch stroke; fitted with Walschaert valve gear operating piston valves with outside admission. The superheater is of the Schmidt type, consisting of eighteen superheater flues arranged in the upper part of the tube plates, in three rows of six flues each. Each flue contains two return tube elements, or four tubes in all. The chart, figure 1, will best describe to the members the general arrangement of the superheater of the type used in the engine under discussion. Two engines of this class are in service and commenced work in November, 1912. They were part of an order for twelve engines made by the North British Locomotive Company of Glasgow in 1912. The ten saturated steam engines are similar in all respects,

but are without the superheater and have cylinders 17 in. diameter and 23 in. stroke. All wheels, rods and motions are interchangeable over the twelve engines. Time did not permit of the redesigning of the valve gear for the superheaters so as to arrange for inside steam admission, and in that respect these engines are admittedly inferior to what could have been obtained under other circumstances.

The great improvements in the lubricating properties of the oils now available and the better methods of applying them have largely solved the problem of working high superheated steam on a locomotive. On these railways we use exclusively a mechanical forced feed. The pump, which is double acting, is operated by a system of levers from a convenient part of the motion. Eight pumps are enclosed in a rectangular tank and are constantly flooded with oil. The stroke of the pump is regulated and a further means of controlling the quantity of oil delivered is provided at the delivery valve. On the steam chest at the points of delivery of the oil, reflux valves are provided to obviate the possibility of the oil being forced back on the pump, thereby stopping lubrication or perhaps flooding the pump chamber with water. These reflux valves are of the utmost importance, and a perfect seat must be kept for the valve or lubrication will become very deficient ; all conductor pipes must be kept full of oil and it is very necessary that drivers see to this fact before moving their engine from the shed, as cutting of valve chambers and rings is readily accomplished with highly superheated steam, if lubrication is wanting. When it is remembered that the pump only makes about four strokes per mile on an engine with a 4 ft. wheel, it will be readily understood that a very considerable distance would be run before even the pipes would be filled and before the oil could reach the moving parts. An engine here, just out of shops, with new valve liners and rings, was rendered practically unworkable through the driver's omission to see that his pump was operating and that the oil was being delivered at the proper point. This damage was done in the first ten miles run, in all probability, and the blow through was so excessive that the engine could not haul the load, and had to be returned to shops for valve liners to be bored out and new valve and rings fitted.

The oil must be of a high flash value, preferably as high as 600° F., but certainly not less than 525° F, if efficiency is to be attained. It is a heavy body, and in cold weather requires to be heated by steam in the pump chamber to permit of an even flow. It should not readily carbonise, but rather volatilize in the steam. Such an oil is obtainable either as a pure mineral or a blend, and is about the same cost as the valve oils used on saturated steam locomotives. The last contracts are for saturated steam 2s. 8d.,

and for superheated steam 2s. 9d. per gallon. In both types of engines the valves and cylinders are given about $1\frac{1}{4}$ pints of oil per 100 miles.

The eight pumps deliver oil to the following points: at both ends of the valve chamber, at both ends of the cylinders, at the piston rod gland, and at the tail rod bush.

The gland packings and their efficiency are largely dependent on the lubrication and especially so on the valve spindle on such an engine as this with outside admission. Metallic packing is generally used, consisting of a mixture of 80 per cent. lead and 20 per cent. antimony. This has worked well in the piston rod gland, but was not satisfactory in the valve spindle, and the metallic packing rings were removed and replaced with pure asbestos, which has given no trouble.

The boiler for the superheated engine is of similar dimensions to the saturated engines of the same class. One hundred and six (106) $1\frac{3}{4}$-in. brass fire tubes in the upper part of the tube plate are being abandoned and replaced by eighteen copper tubes of $5\frac{1}{4}$-in. diameter containing the superheater elements. In this State the economy of boiler repairs will, in my opinion, be equal to the savings effected by the reduced consumption of fuel and water. The saturated engines are designed for a working pressure of 175 lbs. per sq. in. The superheated engines work at 160 lbs., and the cylinder diameter is 19 in., against 17 in. in the saturated carrying the higher boiler pressure. The superheat engines perform their duties in an easy manner and, notwithstanding the increased cylinder diameter, there is always ample steam. Therefore, the boilers not being forced as the saturated type are, the boiler repairs are very low. The greatly reduced coal and water consumption warrants this conclusion, in addition to our experience in maintenance for nearly two years.

A feature of considerable importance, and one not anticipated, is the comfort with which drivers pass through the Swan View tunnel, using superheat steam. Although this tunnel is only some 400 yards long, it is by no means pleasant for the driver of a saturated steam engine. Engines work full out on the down journey, the exhaust steam strikes the roof of the tunnel and immediately fills the cab. The same happens to the superheated, but the dry steam of the latter greatly relieves the conditions; in addition the engine is not working so hard.

No troubles have been experienced in the smoke box headers or the superheater elements. The $5\frac{1}{4}$-in. tubes containing the elements are usually of steel. On account of the bad qualities of our water we were obliged to substitute copper tubes, and so far they have given satisfaction. These Schmidt superheating appliances are of the type providing a set of louvred plates in the

smokebox automatically operated by the regulator, so that when the regulator is closed the louvres are shut, thereby blocking off the superheater tubes from any draught and so preventing the possible burning of the superheater elements. These louvres are adjustable by the driver so as to regulate the amount of superheat. Owing to the temperature reached in the smoke box, these louvres are not easily kept in working order, and there are now at work several arrangements to get over this disadvantage. The Robinson superheater, largely used in England, and which in many respects resembles Schmidt's, substitutes for the louvred damper a series of live steam jets in the smoke box, which prevents the hot gases passing through the superheater tubes when the regulator is closed, the steam jets driving the hot gases back to the firebox.

Schmidt's have recently put on the market a bye-pass and steam circulating valve. This is designed to supersede the dampers in the smoke box and so render inspection more easy. The scheme provided for a small quantity of live steam direct from the boiler to circulate through the superheater elements, thus preventing their being burned, and thence by way of the valve chest to the cylinders and then exhausted to atmosphere. Both ends of the cylinders are placed in communication with each other by means of an external connection, which latter is provided with an intermediate valve, which is automatically closed when the regulator is open. This system appeals strongly to me for several reasons. It reduces the amount of gear in the smoke box, which is difficult to maintain ; this further enables the superheater flues to be efficiently cleaned from the smoke box end ; but the greatest benefit to be derived is by maintaining the temperature of the cylinders, and at the same time the steam admitted would be sufficient to efficiently distribute the lubrication to both valves and pistons. The small amount of steam apparently wasted in this operation would be justified by the results and more particularly as regards lubrication. This system is working well in New South Wales, while on one large railway in England it is reported not to have reached expectations.

In some places no dampers are used, nor are any other means provided for retarding the furnace gases from traversing the large flues. In such cases it is probable that they are not superheating up to 650° F. If they did the superheating elements would undoubtedly suffer near the firebox end and would soon burn out.

Any means of reducing the amount of gear in the smoke box is of considerable importance. It is found almost impossible to take off any nuts or remove pins without destroying them, and particularly where they are closely attached to the parts containing the superheated steam. We have improved these conditions by a free use of graphite and oil when erecting the parts.

The steam headers in the smoke box are of cast steel and are standing well up to their work. Some engineers are now using cast iron and they say with equally good results. This practice is open to grave doubts. Many serious accidents have occurred in cast iron fittings, such as valve bodies, when used with superheated steam.

The question as to the economy in superheating no doubt depends on the amount of superheat. The real efficiency is gained by the reduction or elimination of cylinder condensation. We aim at a temperature of 650° F. or a superheat of 287° F., the temperature of saturated steam being 363° F. at 160 lbs. pressure. On tests spread over a period we maintained an average of 220° F superheat, using Newcastle coal with a calorific value of about 13,500 B.T.U. These temperatures cannot, however, be so well maintained with Collie coal with a calorific value of about 10,000 B.T.U., the temperatures recorded in the fire box of a locomotive using Newcastle coal being 1,290° C. and that of Collie being 1,110° C. When a fire is put on of Newcastle coal there is only a small appreciable drop in the temperature, and that only for a very limited period. With Collie coal, the firebox temperature drops to 500° C., a loss of 600°, and an appreciable time elapses before the maximum temperature is regained. As Newcastle coal only contains 4 per cent. of moisture and Collie up to 24 per cent., this is largely explained. The temperatures were taken with a "Fery" radiation pyrometer focussed through an air space in the firehole door and when the engine was standing. It was not possible to obtain results with the engine steaming as there was too much vibration. When steaming the temperatures were higher.

On a test of a class "Fs" engine, superheated, using in one case all Newcastle coal of a calorific value of 13,500 B.T.U., and in the other Collie coal of about 10,000 B.T.U., in the first case 73 lbs. of Newcastle coal were used per square foot grate area per hour, whereas it took 92 lbs. of Collie. The Newcastle kept an average superheat temperature of 666° F., while the 26 per cent. greater consumption of Collie only maintained an average of 631° F. This is a good performance for Collie coal, and is no doubt due to the superheating. Fig. 2.

At the general meeting of the Institute of Locomotive Engineers, London, in January 1914, the President, Mr. A. J. Hill, Loco. Supt. of the Great Eastern Railway, read a valuable paper showing the ever increasing costs of railway operation, and particularly in the mechanical branch. He, however, found one ray of hope and that was superheating. *Inter alia*, he stated :—

"With the goods engine I have been able to get more definite information as to the actual load drawn, as well as the miles run, and I find that, comparing some results obtained in 1891

with 1913, the consumption of coal per 100 tons load per 100 miles run per square foot of firebox heating surface has increased from 9.7 lbs. to 11.4 lbs., or about 17 per cent. I have been able, also, to compare these results with similar engines fitted with Schmidt's superheater, and the increased consumption mentioned above has entirely disappeared and instead we have a slight decrease. This should, in my opinion, affect the life of the firebox."

In attached appendices are given the trial results of four days' run with a superheated class "Fs," and saturated steam, class "F," engines. The features to which I would draw particular attention being the water and Newcastle coal consumption per ton mile. The superheated engine consumed .257 lb. of coal and 1.76 lbs. water, while the saturated engine used .398 lb. coal and 2.84 lbs. of water, showing a saving of 35 per cent. of coal and 38 per cent. water. These results were obtained under good conditions for superheating, inasmuch as the loading was fairly good and the work was done over a gradient of 1 in 50. Under these circumstances the higher degrees of superheat are more readily maintained, the fuel being a fair quality of Newcastle.

In addition to the class "Fs" locomotives already referred to, we have seven "Garratt" type engines fitted with superheaters of the Schmidt type, and in all respect similar to the "Fs" class.

These engines, however, were designed for the use of superheated steam, and their valves are arranged for internal admission. In consequence there is no difficulty with the valve steam packing, as was at first experienced with those having external admission.

These engines are designated class "Ms." The tests that have been made on them confirm the efficiencies gained. In this case there was a saving in coal of 31.32 per cent. and water 19.3 per cent. by the superheated engine over the saturated steam machine; and in addition the engines perform their work with greater ease in all respects. The saturated steam engine lost 18 to 35 minutes each day through stoppages for steam, and could only with the greatest difficulty haul her load over the banks, and water tanks had to be refilled on the run. Having seven of these engineworking superheat and six working saturated steam, class "M," we have determined that there are no disadvantages introduced with the former, which would tend to balance the economies of coal and water. Considering hat the use of superheated steam is a new feature here, and of wh'ch our enginemen had no previous experience, it is evident that the system may be introduced with confidence elsewhere. These class "Ms" engines have been in service since September, 1913. The class "M" engines were placed on traffic in March, 1912.

The Midland Railway Company of Western Australia hav a number of engines equipped with a smoke box superheater.

The system consists of a double nest of tubes, one at each side of the smoke box, which intercepts the hot gases in their passage from the boiler tubes towards the chimney. It is claimed for this scheme that none of the heating surface is taken from the boiler as in the Schmidt superheater, and that all the advantages are gained exclusively from the gases that would otherwise be wasted. We have, however, proved to our satisfaction that boilers fitted with Schmidt's appliances are free steamers and that although the heating surface in the tubes is interfered with it does not affect the efficiency of the boiler as a steam raiser. The smoke box superheater has, however, many disadvantages which makes it particularly unsuitable for use on the State Railways where Collie coal is used to such a large extent. Our smoke boxes are frequently half filled with ashes; these ashes are occasionally red-hot, and would then probably burn out the superheater, and, if they were not, at normal heat would so reduce the area exposed to the gases as to make the superheater non-effective. A recent test on one of the company's engines showed that the superheat of the steam never exceeded 106° F. and would only average about 50° F. over a run of 95 miles.

Figure No. 3 gives a chart showing the rate of firing, revolutions per minute, and the steam temperatures attained. This chart is of some interest, as it shows how responsive the superheat is to the work being done represented by either the speed or the heavy firing when working up the grades. The temperatures recorded were taken in the steam chest. Newcastle coal was used and should give results indicative of the best that could be attained with this type of gear. The average steam pressure was 168 lbs. per square inch, and average superheat 50° F. With the Government "Ms" engine, with an average steam pressure of 160 lbs., we carry an average superheat of 276° C.

This chart also shows what must take place in the superheater tubes as regard expansion and contraction. These small tubes are rigidly held at the top and bottom of the smoke box, therefore the continual expansion and contraction which takes place puts excesisve work on these tubes, and such a bending process must limit their life. The corresponding tubes in the Schmidt are free to move at their one end under expansion or contraction, and to which no resistance is offered.

It seems to me that with this superheater the steaming efficiency of the boiler must be reduced owing to the restriction of the smoke-box area and the retardation of the flow of the gases. If this is overcome by increasing the blast, the engine must suffer from the back pressure caused thereby.

Figure No. 4, taken from Master Mechanics Proceedings of U.S.A., very clearly points out the relative inefficiency of low superheat. This must be taken as approximate only. The results were obtained by Professor Goss on his test locomotive at the Purdue University. It shows that by increasing the superheat from 50° to 200° the steam consumption falls about 20 per cent. As the greater superheat is not reached with a greater coal consumption but by a better method of heating the steam, the argument for high superheat is very greatly strengthened, if not finally determined.

In conclusion, I would refer to Figure No. 5, which is also Professor Goss' conclusions. It is of particular interest as showing the economy gained by the higher pressures when using saturated steam, but it also demonstrates that such high pressures are not necessary when high superheat is employed. The maximum efficiency with the latter is reached at about 175 lbs. per square inch, and is nearly equal at 160 lbs. per square inch, and all locomotive men will recognise how essential it is to work at the lower figure and by so doing keep away from boiler repairs and water troubles.

As the cost of adding a superheater when making a new boiler is not more than £300, there is a very large margin between the annual savings in coal and water and any possible repairs to the superheater.

A class "Fs" superheated engine running 20,000 miles per annum and hauling an average load of 300 tons behind the engine would save in coal a total of 377.7 tons which, at 24s. per ton for Newcastle coal, equals £453, and the water saved at 2s. 6d. per thousand gallons represents £81, or a total saving of £534. These figures represent the saving on or near the coast, but in the interior, where cost of haulage of the coal has to be added and where we pay two to three times as much for water, the savings would show very handsome results.

I am indebted to the Deputy Commissioner of Railways for permission to place this data before the Institution, also to Mr. Stead, general manager of the Midland Railway Company of W.A., for his consent to obtain results of the working of the smoke box superheater on his railways.

The following appendices are attached :—

1. Test results of class "Fs" superheated steam.
2. Test results of class "F" saturated steam.
3. Particulars of "Fs" and "F" engines.
4. Test results of "Ms" engine, superheat.
5. Test results of "M" engine, saturated.
6. Particulars of "Ms" and "M" engine.

APPENDIX I.

TEST OF CLASS "Fs" SUPERHEATING ENGINE.

Engine Class and No.	Dates of Running.	Days Run.	Coal Used lbs.	Water Used lbs.	Miles Run.	Coal Used per Mile lbs.	Water Used per Mile lbs.	Ton-Miles Hauled.	Coal Used per Ton-mile lbs.	Water Used per Ton-mile lbs.	Steam Temperature.		Average Steam Pressure.
											Maximum.	Average.	
"Fs" 366	26/2/13	1	5,917	40,250	81	73.0	496	22,913	.258	1.75	610	580	150
Do.	27/2/13	1	6,148	42,750	81	75.9	527	24,538	.250	1.73	620	580	150
Do.	28/2/13	1	5,995	42,730	81	74.1	527	23,170	.258	1.84	600	570	150
Do.	3/3/13	1	5,056	33,000	81	62.4	407	19,161	.263	1.72	610	580	150
SUMMARY.													
Do.	26-27-28/2/13 3/3/13	4	23,116	158,750	324	71.3	490	89,782	.257	1.76	610	577	150

Appendix 2.

TEST OF CLASS "F" ORDINARY ENGINES.

Engine Class and No.	Dates of Running.	Days Run.	Coal Used lbs.	Water Used lbs.	Miles Run.	Coal Used per Mile lbs.	Water Used per Mile lbs.	Ton-Miles Hauled.	Coal Used per Ton-mile lbs.	Water Used per Ton-Mile lbs.	Average Steam Pressure.
"F" 362	7/3/13	1	8,253	55,500	81	101	685	21,521	.383	2.57	155
Do.	10/3/13	1	7,421	59,500	81	91	734	18,001	.412	.330	155
Do.	11/3/13	1	8,536	56,500	81	105	697	21,479	.397	2.63	155
Do.	12/3/14	1	7,912	58,000	81	97	716	19,672	.402	2.94	155

SUMMARY.

Do.	7/10/11 12/3/13	4	32,122	229,500	324	99	708	80,673	.398	2.84	155

APPENDIX 3.

PARTICULARS OF CLASSES "Fs" AND "F" LOCOS.

	"Fs" Super heated.	"F" Saturated.
Engine.		
Type	4-8-0	4-8-0
Tender	Eight-wheel	Eight-wheel
Boiler.		
Type	Belpaire	Belpaire
Grate area	18.8 sq.ft.	18.8 sq. ft.
Heating Surface.		
Firebox	125 sq. ft.	126 sq. ft.
Tubes	977 sq. ft.	1,235 sq. ft.
Superheater	261 sq. ft.	——
Total	1,363 sq. ft.	1,261 sq. ft.
Working Pressure	160 lbs. per sq. in.	175 lbs. per sq. in.
Cylinders.		
Number	2	2
Diameter by stroke	19″ x 23″	17″ x 23″
Diameter of piston valve	8″	8″
Admission	Outside	Outside
Motion:		
Type	Walscheart	Walscheart
Outside lap	$\frac{7}{8}$″	$\frac{7}{8}$″
Inside Negative Lead	*Nil.*	*Nil.*
Wheels:		
Coupled. Diameter on thread	3′ 6½″	3′ 6½″
Bogie ,, ,,	2′ 6″	2′ 6″
Tender ,, ,,	2′ 6″	2′ 6″
Weight in working order—	T. C. Q.	T. C. Q.
On coupled wheels	42 14 0	42 9 0
,, engine	55 7 0	54 2 0
,, engine and tender	85 19 0	84 14 0
Water Capacity	2,200 galls.	2,200 galls.
Fuel Capacity	110 cwts.	110 cwts.
Tractive Power	23,445 lbs.	20,530 lbs.

APPENDIX 4.

TEST OF SUPERHEATED CLASS "Ms" ENGINE No. 430.

Date of Test.	Coal Used lbs.	Water Used lbs.	Miles Run.	Coal per Mile lbs.	Water per Mile lbs.	Water per lb. of Coal lbs.	Ton-Miles Hauled.	Coal per Ton-mile lbs.	Water per Ton-mile lbs.	Average Steam Pressure. lbs. sq. in.	Remarks. (Superheat)
15/7/14	2,128	17,500	19	112	921	7.7	4,636	.459	3.77	160	640°
16/7/14	1,848	18,000	19	97	947	9.7	4,617	.4002	3.89	160	650°
17/7/14	1,764	17,500	19	93	921	9.9	4,655	.379	3.76	160	650°
18/7/14	1,792	14,500	19	94	763	7.9	4,426	.404	3.27	160	645°

SUMMARY.

4 days	7,532	67,500	76	99	888	8.9	18,334	.41	3.68	160	646°

APPENDIX 5.

TEST OF NON-SUPERHEATED CLASS "M" ENGINE No. 390.

Date of Test.	Coal Used lbs.	Water Used lbs.	Miles Run.	Coal per Mile lbs.	Water per Mile lbs.	Water per lb. of Coal lbs.	Ton-Miles Hauled.	Coal per Ton-mile lbs.	Water per Ton-Mile lbs.	Average Steam Pressure. lbs. sq. in.	Remarks.
20/7/14	2,688	22,500	19	142	1,131	8.3	4,845	.554	4.64	165	18" time lost
22/7/14	2,800	21,000	19	147	1,105	7.5	4,579	.611	4.59	170	35" do.
23/7/14	2,912	21,000	19	153	1,105	7.2	4,684	.622	4.48	165	36" ,,
24/7/14	2,800	21,000	19	147	1,105	7.5	4,636	.604	4.53	165	25" ,,

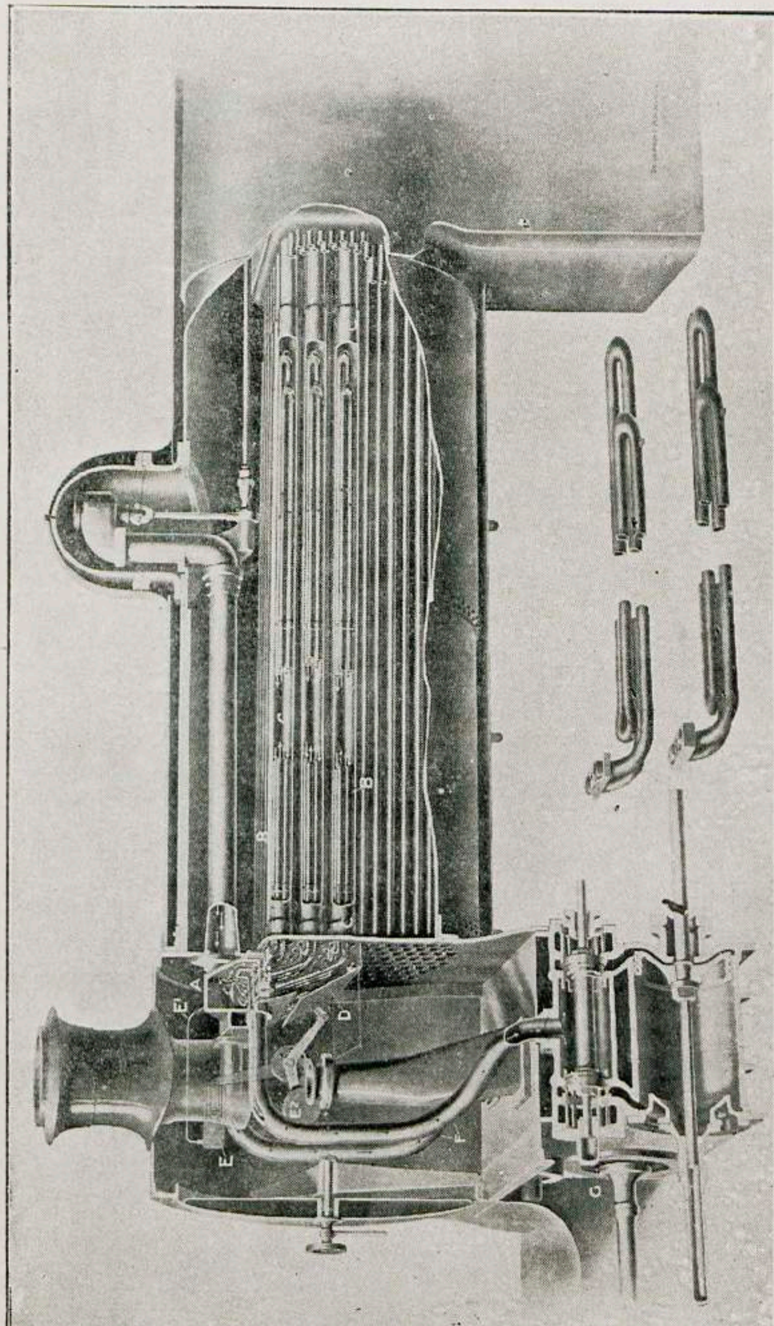
SUMMARY.

4 days	11,200	85,500	76	147	1,125	7.6	18,744	.597	4.56	166	

Appendix 6.

PARTICULARS OF CLASSES "Ms" AND "M" LOCOS.

	"Ms" Superheated.	"M" Saturated.
Engine:		
Type	2-6-6-2	2-6-6-2
Boiler:		
Type	Belpaire	Belpaire
Grate area	22.6 sq. ft.	22.6 sq. ft.
Heating Surface:		
Firebox	107 sq. ft.	107 sq. ft.
Tubes	959.5 sq. ft.	1,233 sq. ft.
Superheater	245.5 sq. ft.	——
Total	1,312 sq. ft.	1,340 sq. ft.
Working Pressure	160 lbs. per sq. in.	175 lbs. per sq. in.
Cylinders:		
Number	4	4
Diameter by stroke	$13\frac{1}{4}''$ x $20''$	$12\frac{1}{2}''$ x $20''$
Diameter of piston valve	$6''$	$6''$
Admission	Inside	Inside
Motion:		
Type	Walschaert	Walschaert
Inside lap	$\frac{7}{8}''$	$\frac{7}{8}''$
Outside Negative Lead	*Nil.*	*Nil.*
Wheels:		
Coupled. Diameter	3′ 3″	3′ 3″
Bogie ,,	2′ 6″	2′ 6″
Weight in working order—	T. C. Q.	T. C. Q.
Coupled Leading	27 8 2	25 13 1
,, Trailing	28 0 3	26 14 0
Bogie Leading	6 16 3	6 19 3
,, Trailing	7 10 1	7 3 0
Total weight	69 16 1	66 10 0
Water Capacity	2,000 galls.	2,000 galls.
Fuel Capacity	60 cwts.	60 cwts.
Tractive Power	21,608 lbs	21,030 lbs.



Locomotive Smoke Superheater—Schmidt's Patent.

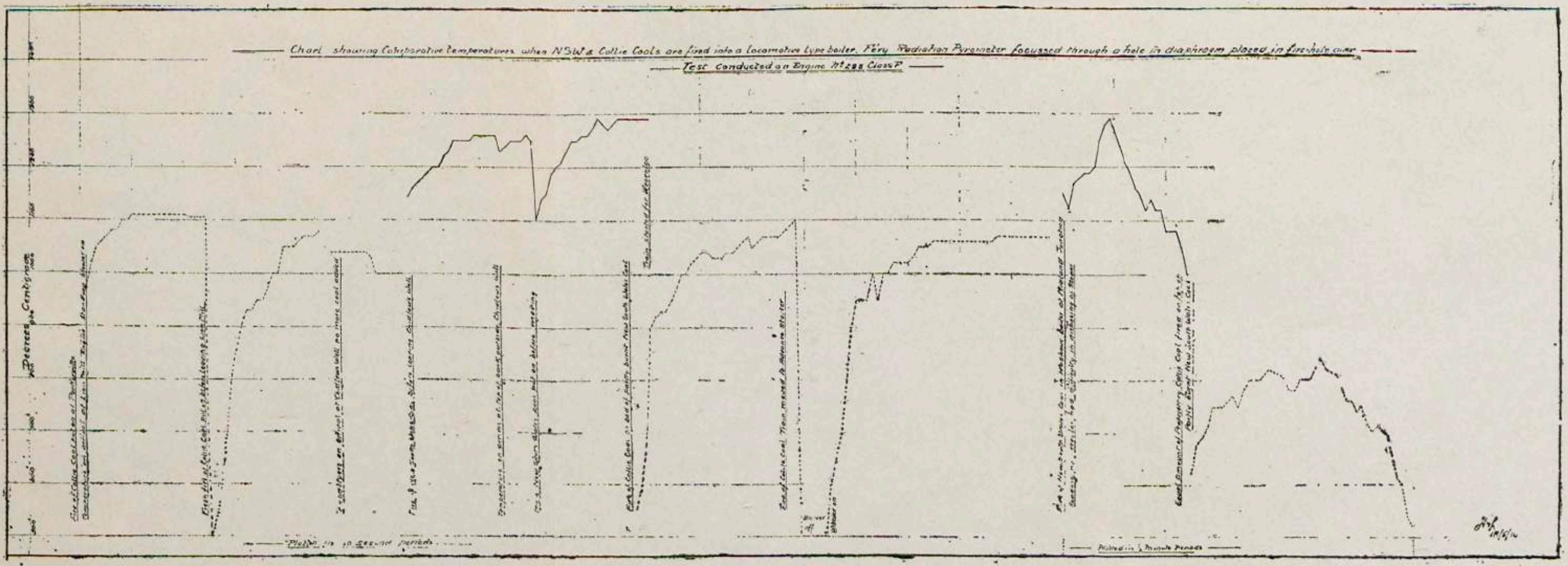


Chart showing Comparative temperatures when NSW & Collie Coals are fired into a Locomotive type boiler. Féry Radiation Pyrometer focussed through a hole in diaphragm placed in fire-hole door
Test Conducted on Engine No 288 Class F
Degrees Centigrade

Fig. 2.

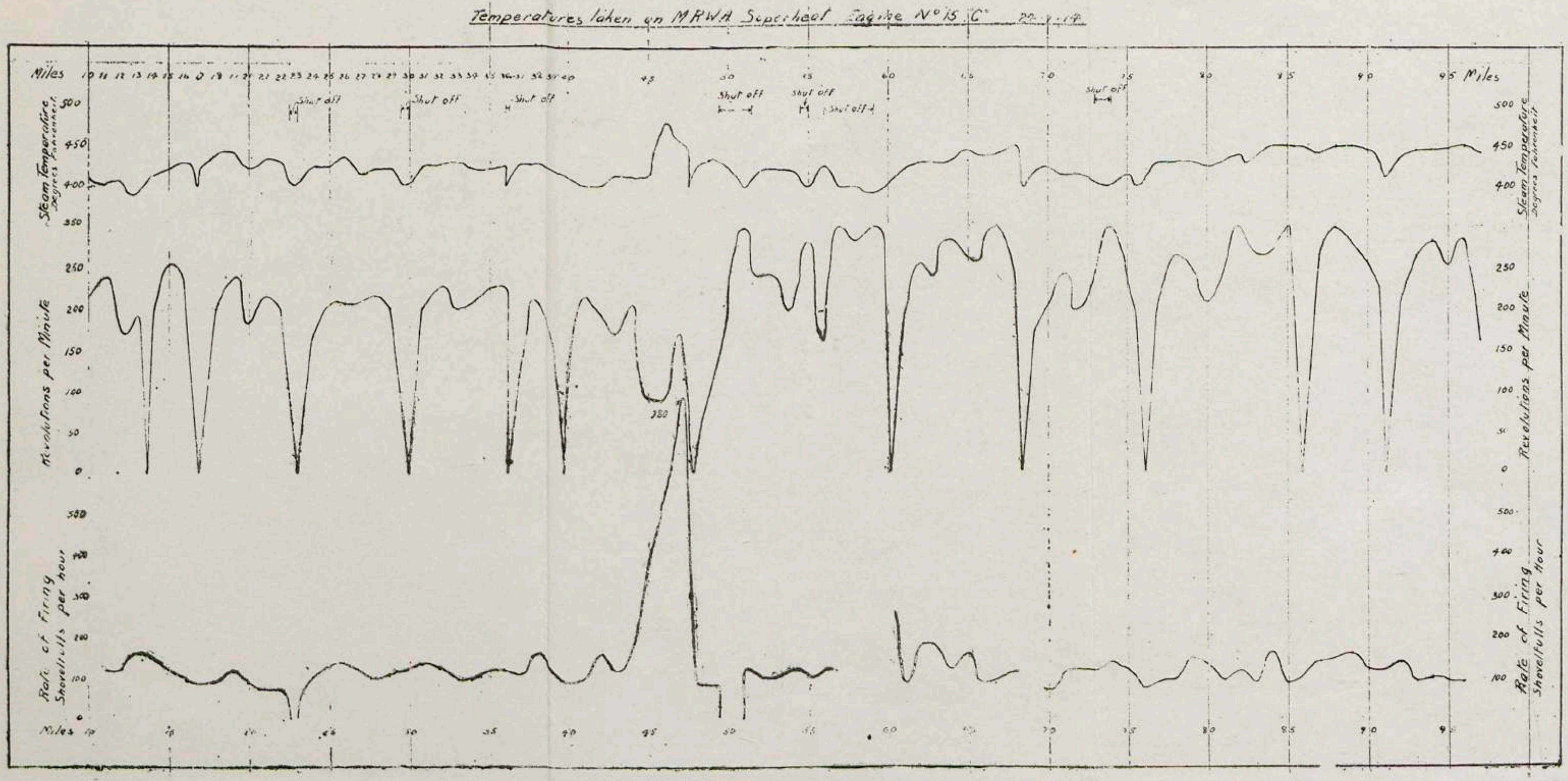

Temperatures taken on MRWA Superheat Engine Nº 15 "C"
Miles
Shut off
Steam Temperature Degrees Fahrenheit
Revolutions per Minute
Rate of Firing Shovelfulls per hour

Fig. 3.

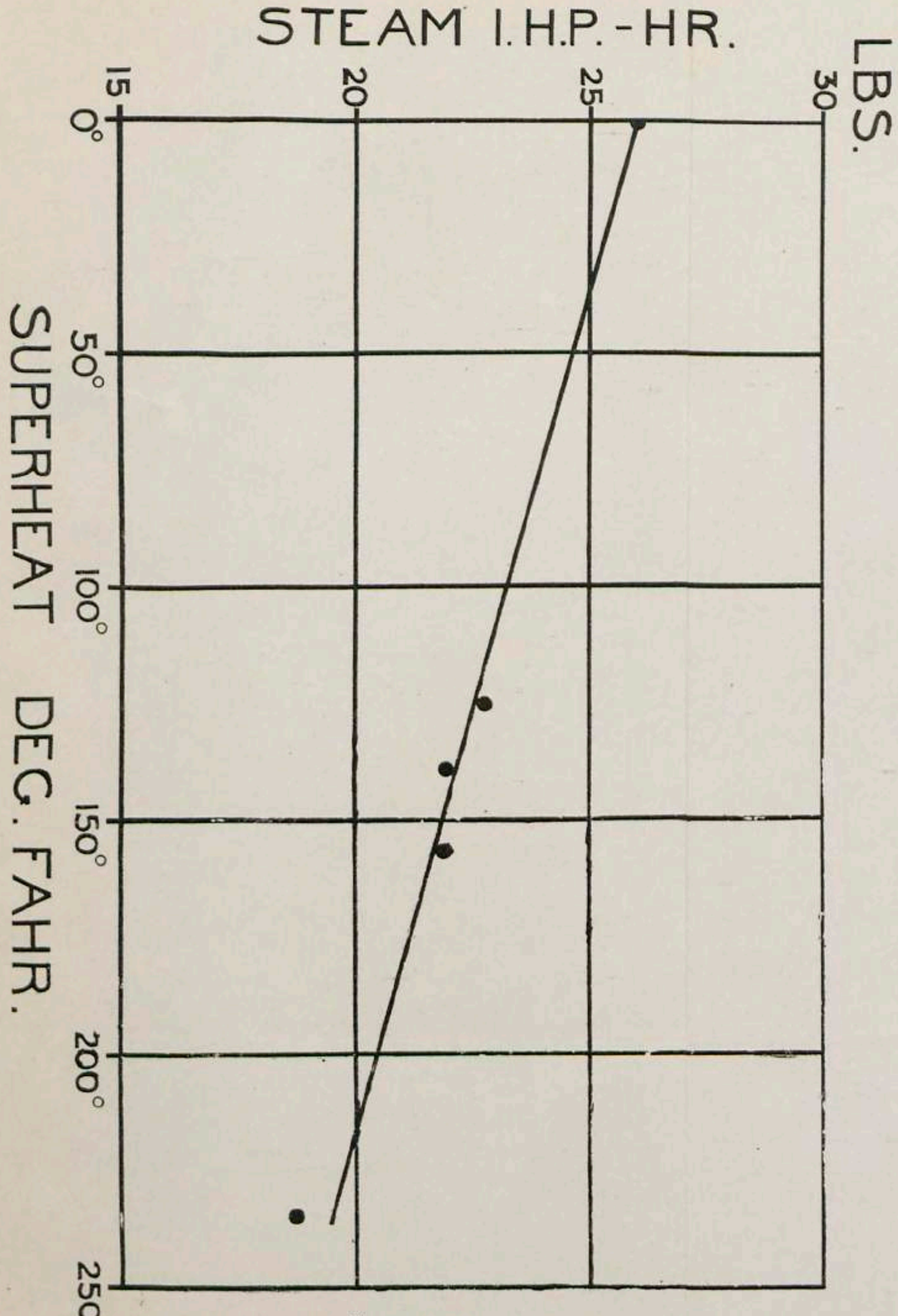

STEAM I.H.P.-HR.
LBS.
15
20
25
30
0°
50°
100°
150°
200°
250°
SUPERHEAT DEG. FAHR.

Fig. 4.

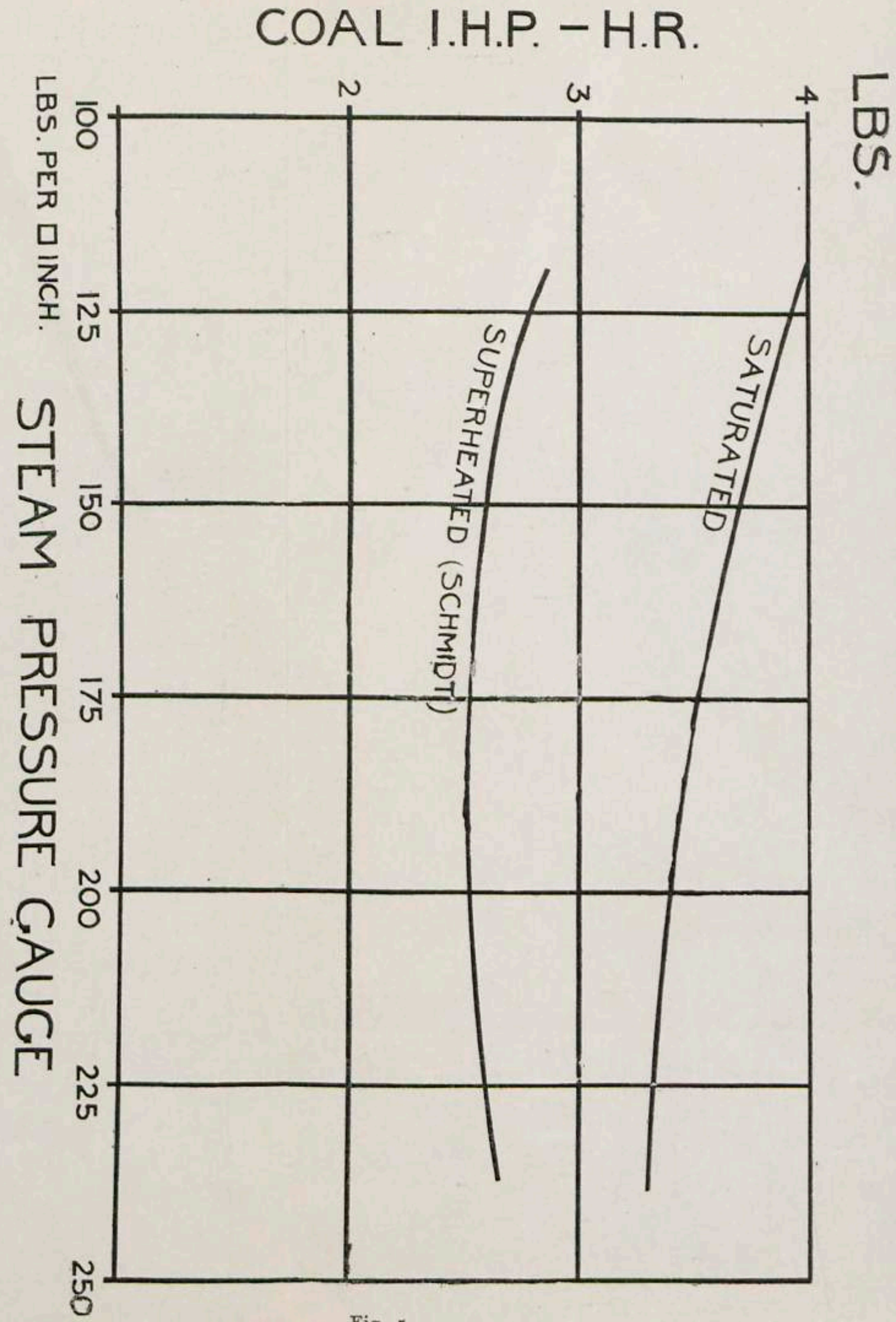

COAL I.H.P. - H.R.
LBS.
2
3
4
LBS. PER □ INCH.
100
125
150
175
200
225
250
STEAM PRESSURE GAUGE
SUPERHEATED (SCHMIDT)
SATURATED

Fig. 5.

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